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ABSTRACT

This publication is a sourcebook for science teachers. It provides guides for basic laboratory work in nuclear energy, suggesting various teacher and student demonstrations. Ideas for science clubs, science fairs, and project research seminars are presented. Problem-solving activities for both science and mathematics classes are included, as well as materials useful for social studies for training civil defense workers in the use of nuclear radiation instruments. Information is given which supplies historical data on atomic energy. An instructional unit, Protection from Radioactive Fallout, is included. A bibliography of publications embracing several aspects of the story of nuclear science and organized by grade levels is included, and a descriptive list of films is presented alphabetically by title. A chronology of steps leading to present knowledge about nuclear science is designed and presented to give teachers and students a better perspective of the whole subject of atomic energy. (EB)

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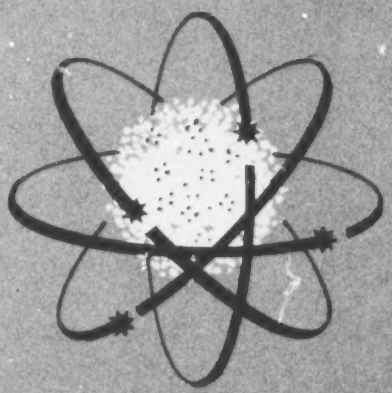
NUCLEAR SCIENCE TEACHING AIDS AND ACTIVITIES



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NUCLEAR SCIENCE TEACHING AIDS AND ACTIVITIES

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Foreword

It takes little stretch of the imagination in this, the 20th century, to associate the continuation and expansion of our American ideals and way of living with the need for adequate numbers of people, young and old, to have the ability to interpret and take part in scientific enterprise. Bringing this fact most sharply into focus is one of the recent developments in science: nuclear energy and its military and peacetime uses.

This sourcebook of teaching aids and activities was prepared under a delegation of authority by the Office of Civil and Defense Mobilization to the Department of Health, Education, and Welfare. The Office of Education, in turn, provided technical assistance to departments of education in three State pilot centers. Teachers in these three States—California, Connecticut, and Michigan—in cooperation with Dr. Woodburn had a major part in designing and trying out the experimental instructional activities and materials reported in this publication. The work at the pilot centers has also produced three previous publications: *Significant Concepts in Nuclear Science* (California State Department of Education), *Nuclear Energy for Beginners* (Connecticut State Department of Education), and *Nuclear Science in the Classroom* (Michigan State Department of Public Instruction).

Nuclear science includes many concepts and principles of science, both natural and social. Few other topics hold as great a challenge for teachers seeking teaching techniques and activities for young people. We hope all teachers can find something in this publication which will help them strengthen their students' understanding, expand their hopes, and allay any fears which nuclear science may hold for them.

LAWRENCE G. DERTHICK,
Commissioner of Education.

Preface and Acknowledgments

The most recent science textbooks and courses of study for high schools almost without exception contain sections on nuclear science. These new publications still need, however, to be adapted to laboratory and demonstration teaching; and trained personnel are needed who could handle instruments for detecting nuclear radiation in case of a national emergency.

The present publication on laboratory and demonstration procedures has been prepared in response to the widely felt needs. Science teachers will find it a source book for the following purposes:

- To guide basic laboratory work in nuclear energy.
- To suggest teacher and student demonstrations.
- To augment projects for talented students.
- To provide ideas for science clubs, science fairs, and project research seminars.
- To afford problem-solving activities for both science and mathematics classes.
- To help train civil defense workers in the use of instruments for detecting nuclear radiation.
- To serve as material for social studies.
- To supply an historical background on atomic energy.
- To describe various aids for enrichment of study units on atomic energy.

The Office of Education acknowledges with gratitude contributions to this publication from the following persons: Roy E. Simpson, Superintendent of Public Instruction, California State Department of Education; William J. Sanders, Commissioner of Education, Connecticut State Department of Education; Lynn M. Bartlett, Superintendent of Public Instruction, Michigan State Department of Public Instruction; Frank B. Lindsay, Chief, Bureau of Secondary Education, California State Department of Education; Arthur Goldberg, Director, Civil Defense Education Project, Connecticut State Department of Education; L. Wayne Berry, Coordinator, Civil Defense Education Pilot Project, Michigan State Department of Public Instruction; and the Education and Training Staff of the Office of Civil and Defense Mobilization.

In addition, the science teachers in the three Pilot Center States should receive special mention for having developed many of the demonstrations described in the publication.

The publication was prepared under the direction of Paul MacMinn, then Chief, Civil Defense Education Project, Office of Education.

WAYNE O. REED,
Deputy Commissioner of Education.

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Chapter I

Introduction

From time immemorial, mankind has been surrounded by *chemical* reactions. Man's response to the effects of these gradually evolved from abject fear to familiarity and, eventually, utilization. Fire, a dramatic property of one chemical reaction, ceased to be something to fear and came to be recognized as a source of friendly warmth. Man learned that heat could be used to make his food taste better, to extract useful metals from their ores, and eventually propel his automobiles along the highway, or his rockets through space.

By the end of the 19th century, the phenomena that accompany chemical reactions had lost nearly all their mystery. Scientists could recognize how atoms and molecules behave in relation to each other and predict with some degree of confidence what would happen when one kind of material reacts with another. Man had learned to duplicate many useful materials heretofore produced only in nature. He understood many natural chemical processes. Even the life process was beginning to lose some of its mystery and many drugs and medicines were produced to maintain good health or cure disease.

But the end of the 19th century brought with it some events and circumstances that could not be explained in terms of the reactions of atoms and molecules. The concept of "solid, massy, hard, impenetrable, movable particles so very hard as never to wear or break to pieces," as theorized by Sir Isaac Newton, became suspect. This was so even though John Dalton had "discovered" that all bodies of sensible magnitude consist of a vast number of extremely small particles, or atoms of matter bound together by a force of attraction. Further, Dalton helped man gain a clearer picture of chemical reaction by theorizing that atoms of a pure substance are all exactly alike in size, shape, and weight and that a chemical reaction is merely reshuffling or recombining atoms involving no change in the atoms themselves.

During the 19th century, many scientists investigated the peculiar glow which accompanied the passage of electrical discharges through glass tubes. The luminous glow from evacuated tubes led some scientists to hypothesize the existence of streams of subatomic particles carrying electrical charges. The study of electricity led other scientists to believe that electricity comes in discrete units or packages. The behavior of cloud droplets caused certain scientists to strengthen the hypothesis that there is a unit of electrical charge. Eventually the electron had to be invented in order to explain these many new observations.

Near the close of the 19th century, Becquerel made his famous observations about the radiation which seemed to come from uranium salts. He saw it penetrate materials which are opaque to ordinary light. He saw it discharge the gold-leaf electroscope. Eventually, scientists realized that some of this radiation which comes naturally from the disintegration of uranium was the same as that which was produced artificially in evacuated tubes. The "indestructibility" of the atom had been destroyed.

The hundreds of individual discoveries and explorations which compose the drama of man's study of atomic structure and nuclear energy provide brilliant examples of scientists at work. They illustrate clearly how projects in natural science often originate in the curiosity of persons who see something in their natural environment that suggests the action of a scientific principle or natural law. Some authors have attempted to tell the story of nuclear science—a story to which justice cannot be done when condensed into the space available in this publication. It would be well, however, for the reader to refer to the Chronology of Steps Leading to Our Present Knowledge About Nuclear Science. This chronology indicates the scope and sequence of this research and provides perspective on the drama as a whole.

Chapter II

Visualizing Atomic Nuclei and Nuclear Reactions

Nuclear radiation consists of fragments of atomic nuclei, packets of energy emitted during nuclear activity, or fragments of the particles which make up the nuclei. The very nature of nuclear radiation makes it difficult to describe. Furthermore, many persons have an almost mystical attitude toward it. It is natural, perhaps, to fear or at least be uncomfortable in the presence of anything we do not understand, especially if it involves phenomena beyond the range of the usual sensory perception. We can neither see, hear, taste, smell, nor feel nuclear radiation. Its presence may be detected only when it produces some secondary effect.

When approaching the topic of nuclear science the teacher is faced by a 3-fold task: he must provide for his students a reasonably realistic and working picture of atoms, clarify the kinds of reactions which involve atomic nuclei, and establish a working acquaintance with the characteristics of the radiation which accompanies nuclear reactions.

A Word Picture of the Atom

A very illuminating description of an atom is given in Wolfgang Pauli's *The World of Life*:[1]

> If an atom could be magnified to the size of a house, it would probably look something like a great soap bubble, except that its outlines would be so hazy and indistinct that it would be impossible to tell just where the borders of the atom were. Within the misty outer shell would appear other more or less concentric or interlocking shells, each as hazy as the outer one. Deep in the center of this shimmering mass would be a denser, more solid looking structure, the nucleus, no larger than a dot. Most impressive perhaps, would be the vast emptiness of the atom, a characteristic which it shares with all the universe around it. It is strange indeed to realize that man and all living things, the earth, and all the universe are constructed of such empty and seemingly fragile structures. It has been estimated that if all the atomic constituents of the human body could be packed together tightly, eliminating the spaces between them, they would be no larger than a grain of sand.
>
> The planetary electrons which revolve around the nucleus must be visualized as endowed with a smashing, driving energy. Even in this house-sized atom, they would revolve in their orbits with such inconceivable speed that they would not be recognized as separate units, but would give the illusion of thin, transparent shells, as unreal as the disk described by the whirling blades of an electric fan. If their speed could be reduced so that they could be made visible, they might become vaguely outlined and intensely vibrating "objects" no larger than pinpoints: not solid, but rather, says modern physics, whirlpools of energy, foci of energy, or similar intangible units.

To Pauli's smashing, whirling picture of the atom, we must add even more activity when we consider unstable nuclei, which we are forced to do when nuclear radiation is involved. In the presence of unstable nuclei there can be a no-man's land where rifle bullets whiz by, bazooka rockets whistle about, and hand grenades are tossed around. It is difficult to associate this metaphor with "the illusion of thin, transparent shells, as unreal as the disk described by the whirling blades of an electric fan." But such is one of the purposes of this publication.

Classifying Nuclear Reactions

Just as chemistry teachers simplify the presentation of chemical reactions by classifying all chemical reactions into a few types, nuclear reactions can be classified according to the radiation or particles which they produce. These products are: alpha, beta, neutron, or other subatomic particles or gamma radiation.

Examples of each kind of nuclear reaction can be found in the history of nuclear science, or we may look for them in its more recent applications.

[1] New York: Houghton Mifflin Co., 1946, pp. 31 and 32.

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Nuclear reaction which produces alpha particles may produce a variety of disintegration products including alpha particles. An example is the natural disintegration of uranium. Just as chemists have devised a kind of shorthand to show chemical reactions, so physicists have developed a shorthand to show nuclear reactions. Thus, the disintegration of uranium can be shown as follows:

$$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$$

In this shorthand fashion of showing nuclear reactions the lower numbers indicate the number of protons in the nucleus and the upper numbers indicate the total number of protons and neutrons—the atomic weight of the atom. Since alpha particles are equivalent to the nucleus of the helium atom, they usually carry the He symbol.

The much-publicized decay of strontium 90 can illustrate that type of nuclear reaction in which beta particles are emitted. Strontium 90 can be one of the products of the fission of uranium 235, a reaction usually cited as an example of the type of reaction which produces gamma rays. Strontium 90 appears as the unstable product of the decay of other unstable nuclei, usually in a four-step process. The shorthand version follows:

$$_{36}Kr^{90} \rightarrow {}_{37}Rb^{90} + {}_{-1}\beta^{0}$$
$$_{37}Rb^{90} \rightarrow {}_{38}Sr^{90} + {}_{-1}\beta^{0}$$
$$_{38}Sr^{90} \rightarrow {}_{39}Y^{90} + {}_{-1}\beta^{0}$$
$$_{39}Y^{90} \rightarrow {}_{40}Zr^{90} + {}_{-1}\beta^{0}$$

An example of a nuclear reaction which yields neutrons can be found in one of the common laboratory neutron sources. If alpha particles from radium are allowed to bombard beryllium, they liberate free neutrons. The reaction is as follows:

$$_{4}Be^{9} + {}_{2}He^{4} \rightarrow {}_{6}C^{12} + {}_{0}n^{1}$$

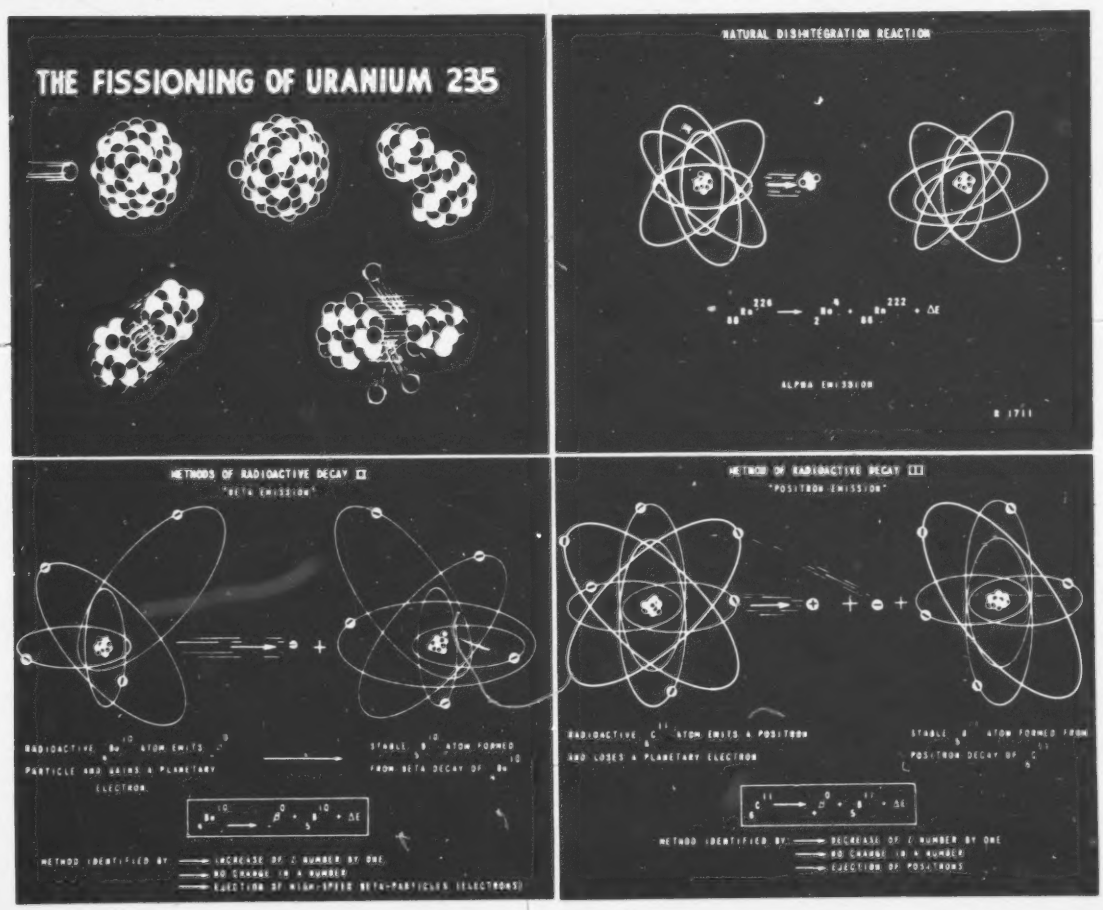

FIGURE 1.—Chalkboard sketches suggesting how nuclear reactions occur.

In preparing a neutron source, the physicist mixes finely divided radium chloride with powdered beryllium in a small capsule. One milligram of radium will yield between 6 and 12 thousand neutrons per second, depending upon the size of the radium chloride grains.

The splitting of the uranium 235 nucleus provides a good illustration of the type of nuclear reaction which produces gamma radiation. This particular reaction produces a wide variety of fission products. A representative reaction is the following:

$$_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{92}U^{236} \rightarrow {}_{42}Mo^{95} + {}_{57}La^{139} + 7\,{}_{-1}B^{0} + 2\,{}_{0}n^{1}$$

For example, uranium 235 + a neutron produces uranium 236, which may split into molybdenum 95 + lanthanum 139, providing 7 beta particles and 2 neutrons. It can be seen that the fission of uranium 235 also produces beta particles.

Modeling Atomic Nuclei and Nuclear Reactions

Recalling the word picture of the atom which appears earlier in this chapter and recognizing this picture may be only a first approximation

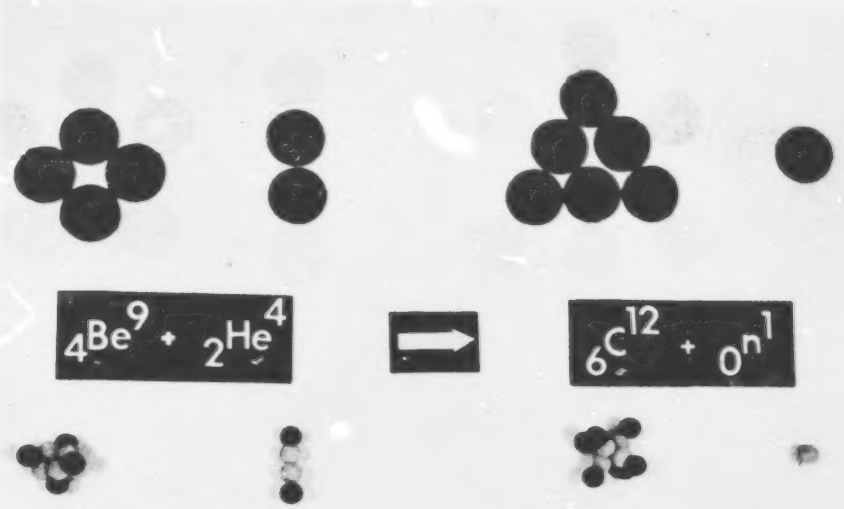

FIGURE 2.—Combining blotting paper circles and styrofoam spheres against a flannel board background to visualize a reaction which provides a source of neutrons.

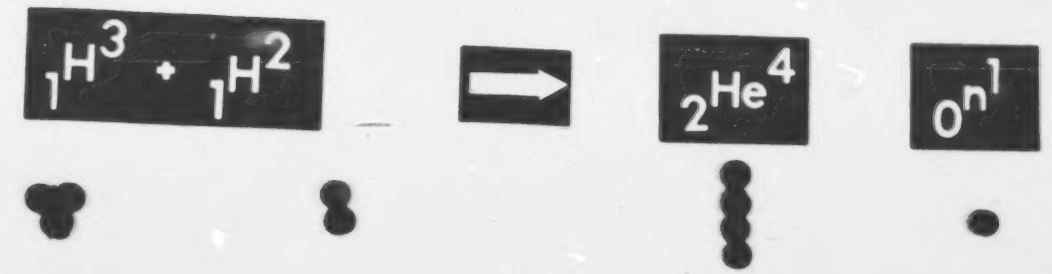

FIGURE 3.—Balls of modeling clay being used to show the last step in a hypothetical hydrogen bomb reaction.

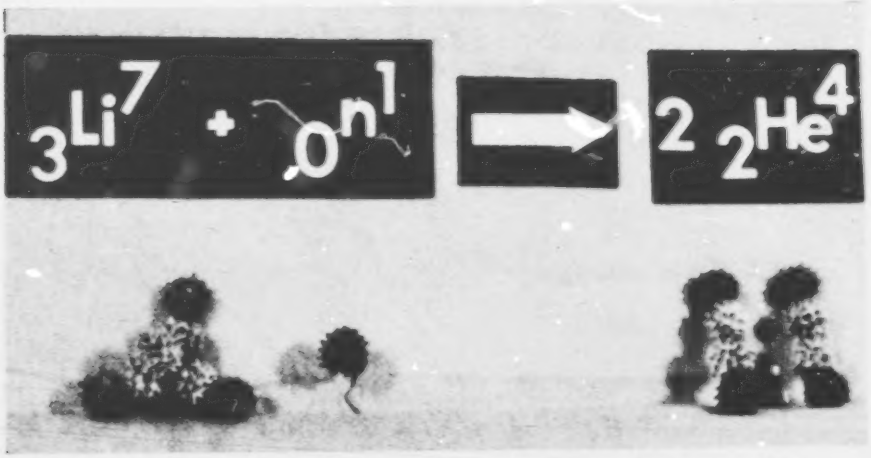

FIGURE 4.—Seed pods from sweet gum trees dipped in paint and dried are used to represent protons and neutrons. They are held together with bits of modeling clay. Would a more compact arrangement of the alpha particles produce fewer misconceptions?

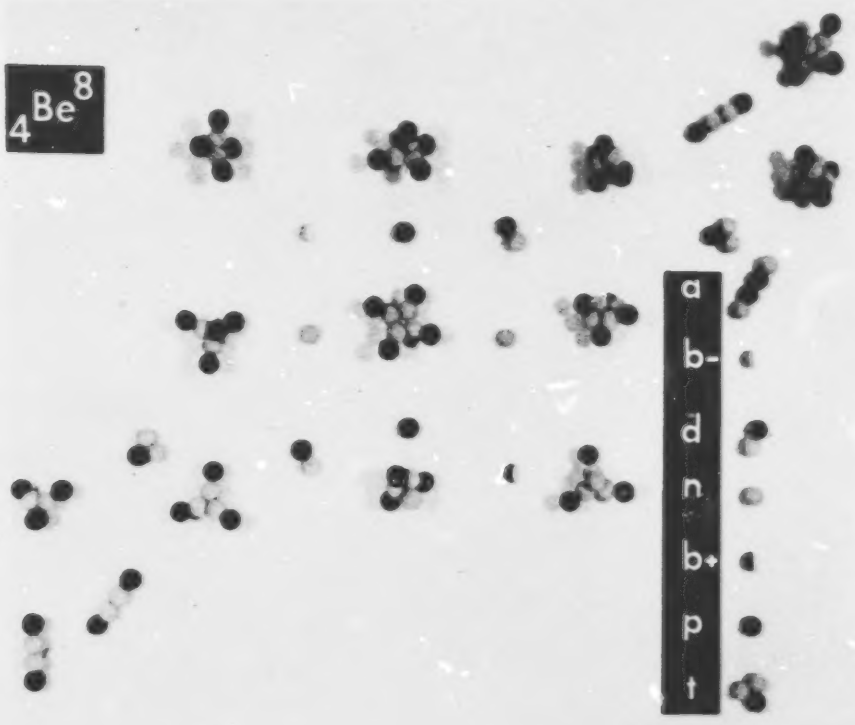

FIGURE 5.—James Stokley has summarized many nuclear reactions in his chart, *Nuclei and Isotopes*. Styrofoam balls against a flannel board background may be used to demonstrate the Stokley chart. In the example, beta emission from a beryllium 8 nucleus would produce the new nucleus found one place to the upper left diagonal. Alpha capture would produce the nucleus shown two places to the right and up two places.

to a true description of the atom, one can appreciate that modeling atomic nuclei and their reactions carries the risk of causing many misconceptions. The limitations of the model must be kept in mind. Models can, however, clarify certain concepts and the resourceful teacher can exploit the shortcomings of the model to emphasize the more theoretical aspects of atomic structure. Efforts to visualize atomic nuclei and their reactions reflect the ingenuity of teachers and their ability to use whatever materials are at hand. Some suggestions may be gained from figures 1 through 7.

Their limitations notwithstanding, models of atomic nuclei can show that protons and neutrons form the atomic nuclei. How these units are arranged and in what form the "binding energy" or "nuclear glue" should appear,

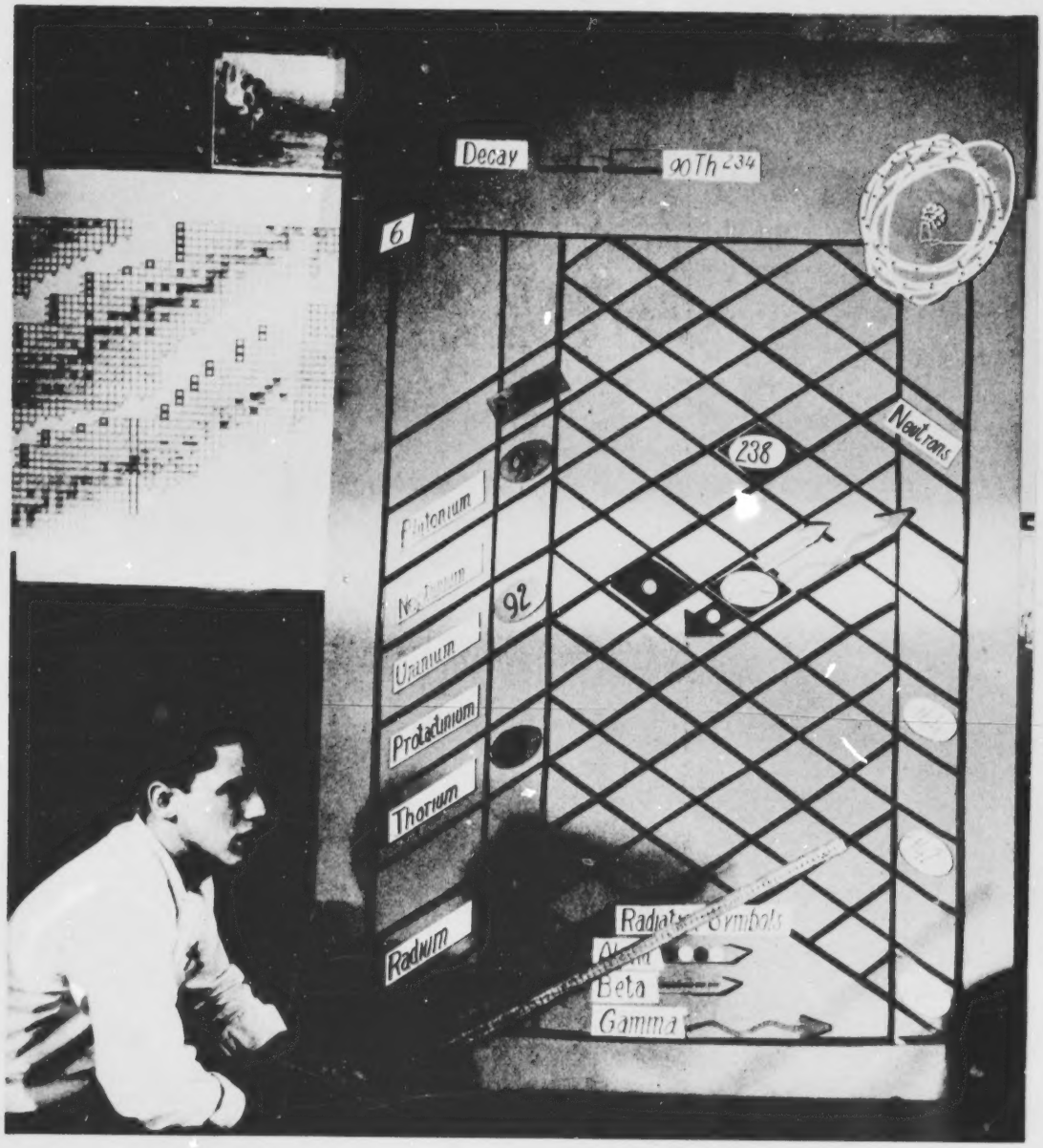

FIGURE 6.—Gordon Swicks, a student of David Schubert in the Sexton High School, Lansing, Mich., shows how the Stokley chart can be interpreted with another kind of flannel board arrangement.

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however, forces one to commit himself to a single point of view regarding phenomena about which there may be many points of view. Limitations of the models impose additional restrictions. One model can show, for example, a beta particle coming from a neutron, thus forming a proton. The proton, in turn, can be shown to emit a positron. Students can now well ask how this neutron differs from the original neutron.

Styrofoam-ball models of unstable nuclei help students relate radiation to its sources—something they must succeed in doing before they can handle radioactive materials intelligently. Wires of appropriate length can be stuck into the nuclei and symbolical beta or gamma "particles" placed on the ends of the wires. Again, the limitations of the models must be kept in mind. The lengths of the wires will be completely out of scale with the size of the nucleus, but their lengths can be used to show the relative energies of the emitted particles. Visualization of the gamma rays is especially difficult. Plastic tubing or insulation slipped over the end of the wire and bent into wave form will at least suggest the wave nature of the gamma ray. Keeping the "wave" in a compact "bundle" will suggest its particulate characteristics.

Models, despite their limitations, reduce the mystery of nuclear radiation by reducing it to simple products of nuclear reactions involving either unstable nuclei or interactions between nuclei or portions of nuclei. As the student advances toward a more sophisticated stage, models bring sharply into focus many questions regarding the arrangement of nuclear particles and the maintenance of stability or instability.

Additional ideas of modeling nuclei and nuclear reactions appear in the bibliography.

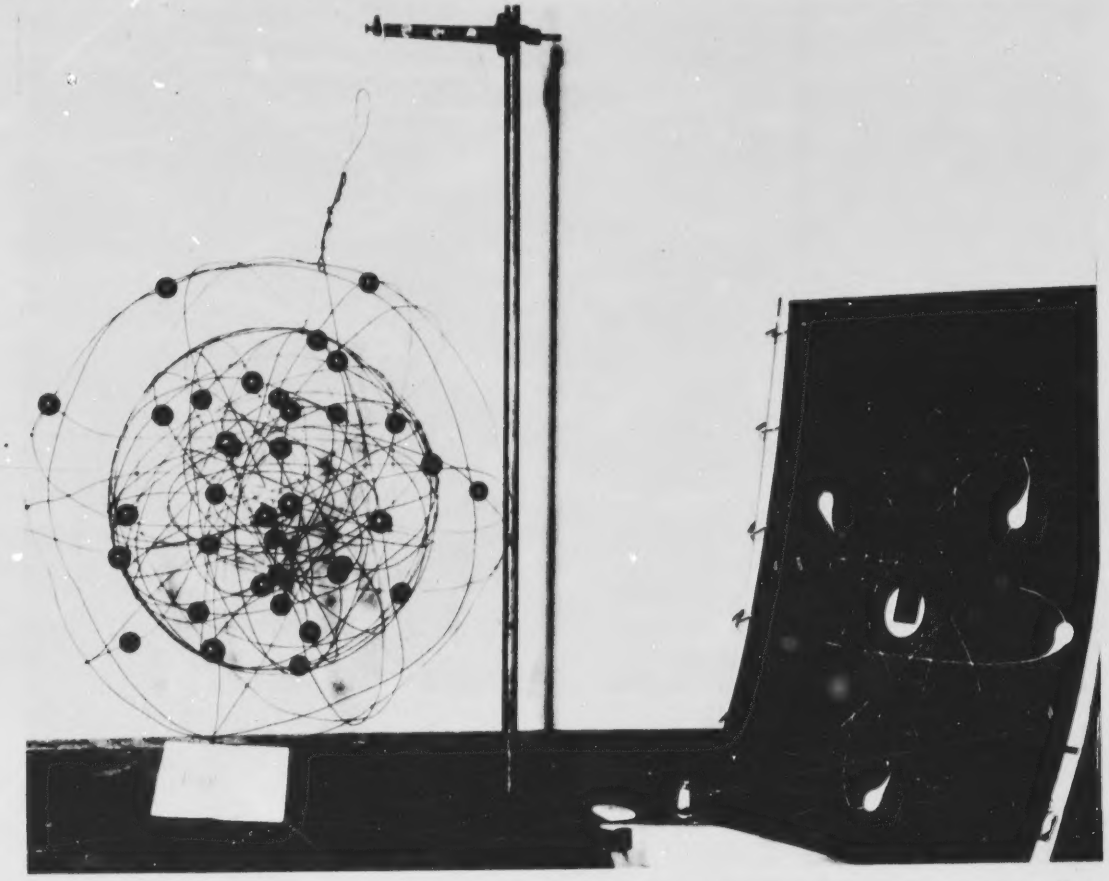

FIGURE 7.—Two students at the T. L. Handy High School, Bay City, Mich., turned out on a lathe wooden balls to portray the krypton 82 atom. This portrayal includes the orbital electrons.

Chapter III

Getting Acquainted With Nuclear Radiation

We need to call upon no scientific principle more complex than the simple conservation of energy to realize that alpha, beta, gamma, and other nuclear radiation tends to transfer energy to atoms with which it comes into close contact or collides. By recalling our earlier word picture of the atom, we can easily understand why most of the phenomena associated with the collisions involve the orbital electrons. Atoms whose orbital electrons have been removed exhibit the properties of ionization. Thus our problem of becoming acquainted with nuclear radiation brings us, for the most part, to an understanding of ions and ionization.

If a phenomenon depends upon atoms being combined in molecules by ionic processes, we can expect that phenomenon to be affected by the presence of nuclear radiation. Many of the biological effects of radiation are so originated. Similarly, we would expect nuclear radiation to affect a photographic emulsion if the chemical compounds in the emulsion are sufficiently unstable to be affected by ionizing radiation.

When we work with nuclear radiation, we may expect to recognize each of the characteristics of ions. Electrical fields produce ion movement. Their energy is converted into some other form. They may serve as condensation nuclei in cloud or bubble chambers. These and other effects can be traced to disturbances in the arrangement of the orbital electrons around an atom.

The accompanying sketches (figure 8) show one artist's attempt to illustrate nuclear radiation and the production of ionized atoms.

Sources of Nuclear Radiation

The widespread use of radioactive isotopes for tracers and other peacetime purposes has resulted in a wide variety of unstable nuclei being available from commercial laboratories. No special licensing is required to purchase small quantities of many of these isotopes. Several suppliers have indicated willingness to sell them and each shipment usually includes a copy of the regulations governing distribution and handling of radioactive material.

To work comfortably, confidently, and in-

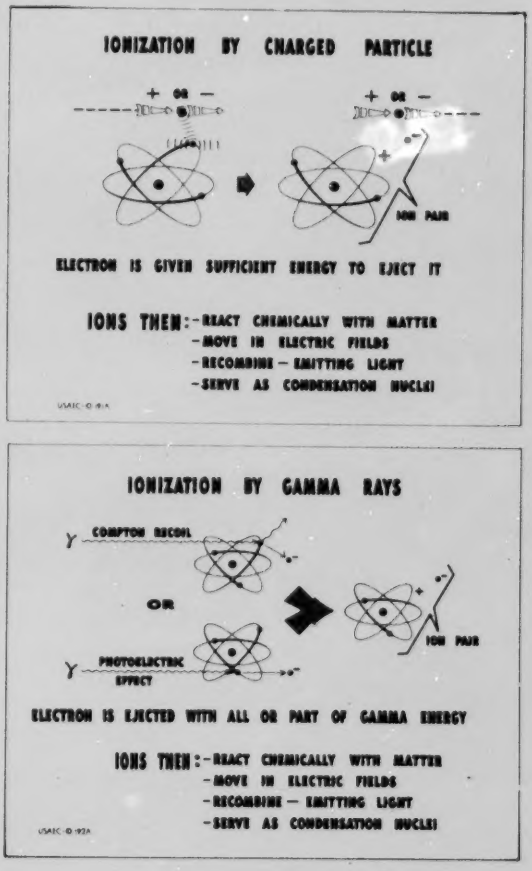

FIGURE 8.—A set of instructional charts prepared by the U. S. Atomic Energy Commission.

telligently with nuclear radiation, one needs answers to the following questions:

- What nuclear reaction is producing the radiation?
- How much of the reacting material am I responsible for and where is each bit of it?
- What are the characteristics of the specific radiation with which I am working?
- How can it be used to do something worth doing?
- How can I keep to a minimum the chances that this radiation will do something that should not be done?

One commercial supplier who provides small quantities of radioactive materials for classroom demonstration or experimental purposes features nine isotopes in a small pack ("jumbo" pack). The isotopes are selected so as to provide a range of half-lives, a range in the energies of the particles emitted, and a variety of radiation.

Radioactive Materials

Quantities of radioactive material are usually expressed in terms of microcuries, millicuries, or curies. A microcurie quantity of any radioactive material contains enough unstable nuclei to allow 3.7×10^4 (37,000) disintegrations per second. In other words, a 10-microcurie quantity of phosphorus 32 would have 370,000 phosphorus 32 atoms disintegrating per second. No one can proceed intelligently with the handling of any radioactive material if he does not know precisely its microcurie rating. This fact becomes especially apparent when one is using luminous dials or other casually obtained sources of radiation.

Various charts and handbooks summarize the type and characteristics of radiation emitted from all known unstable nuclei. An example is the Table of Isotopes by D. Strominger, J. M. Hollander, and G. T. Seaborg.[1]

Iodine 131 has a relatively short half-life, 8 days. It emits 0.60 and 0.32 Mev maximum energy beta particles and gamma rays with energies approaching 0.08 and 0.64 Mev. These energies are in the medium range of radiation produced by the more commonly available isotopes. Phosphorus 32 (half-life of 14.3 days) emits only beta particles with a maximum energy of 1.7 Mev. These are relatively high energy beta particles. Sulfur 35 (87 days half-life), emits 0.17 Mev beta particles. These are relatively low energy betas. In fact, beta particles with much less energy are scarcely adequate to expose photographic emulsions unless in high concentrations or by very long exposures. Zinc 65 (250 days half-life) decays by electron capture, producing 0.32 Mev positive beta particles and 1.11 Mev gamma rays.

The data given above are representative of the information one needs to plan experiments using radioactive materials. Unless the information is well in hand before ordering isotopes, especially the short-lived ones, the material may decay before the experiments are underway or may lack the characteristics necessary to insure success for the experiments. The tendency of nuclear radiation to transfer energy to atoms with which it collides causes it to be potentially dangerous, but it is this characteristic that makes it useful and which is the basis of design of instruments or techniques of radiation study. Nuclear radiation, for example, is detected by its ability to register on photographic film or to affect specially designed instruments. Autoradiography is an example of the first process.

Principles of Autoradiography

The basic idea of autoradiography is to bring a sample, such as thin slices of biological materials, smears of fluid tissue, organs, organisms, or other objects containing radioactive isotopes into contact with a photographic emulsion which, after suitable exposure, is developed and fixed. The origin of the process can be traced directly to Becquerel's accidental discovery that a fragment of uranium ore lying near a photographic plate caused darkening of the plate even though the latter had been protected from light by opaque paper. As the accompanying photograph indicates, it did not take long for scientists to apply this new technique in their investigations (fig. 9).

The basic principle underlying autoradiography is that alpha particles, beta particles, gamma rays, or other nuclear radiations ionize molecules along their paths. This ionization leads to the chemical reduction of silver atoms in halogen compounds contained in the photographic emulsion in about the same way light acts on silver salts. Each silver atom struck by a "bullet" from a radioactive isotope parts company from its bromine or other halogen

[1] Published in the American Institute of Physics' *Review of Modern Physics*, 30: 2: 585, April 1958.

FIGURE 9.—Radioautograph of biological application of Becquerel's discovery (radioactivity of uranium salts). A frog, placed in a hermetically sealed jar to which was connected a tube of radium, was exposed to its vapors and on the 12th day died and was photographed.

atom and becomes an atom of free silver. Each of these free silver atoms, during the developing process, tends to accumulate crystals of silver around it. Thus, during this same developing process, those silver atoms which were missed by the alpha, beta, gamma, or neutron "bullets" are washed from the photographic plate. They will not thereby be reduced to free silver if the plate is exposed to light, a process that is necessary if we are to look at our radiographs. The silver atoms which were hit by "bullets," on the other hand, will remain on the plate to show us where the "shooters" found their targets. These targets form opaque silhouettes on the photographic film. A more advanced version of this process, in *Radiation Dosimetry*,[2] is the following:

The exposing agent transfers some of its energy to the silver bromide crystal, thereby raising the energy of one or more electrons into the conduction energy band of the crystal. These electrons then travel through the crystal until trapped in sensitivity centers, which might consist of impurities or deformities in the crystal lattice. The electrostatic potential set up about these centers brings into action a second process. A certain very small fraction of silver ions in the crystal is free to migrate through the crystal, the fraction depending largely on the temperature. These ions are attracted to the trapped electrons and neutralized to form silver atoms. Under continuing exposures these two processes continue until a group of silver clumps, containing one to several silver atoms each, are distributed throughout and on the surface of the crystal. These clumps constitute the latent image and catalyze, during the development process, the chemical reduction of the remainder of the ionic silver in the grain.

Tracers are so convenient to use whenever one wants to keep track of some element and watch what it does and where it goes that recent issues of many scientific journals report new examples of autoradiography in solving problems. Autoradiography, in turn, provides a permanent record of the tracing investigations. Some examples follow:

Using material from a patient poisoned by radium, Gettler and Norris in 1933 placed bone and other tissue ashes on photographic film which had been wrapped in black paper. The bones were found to be strongly radioactive, whereas the soft tissues were only weakly so.

Behrens and Baumann in 1933 sanded smooth one side of normal and pathologically changed bones and exposed the smooth side to film. They found that radioactive lead seemed to deposit itself in the bone depots where calcium tends to collect.

Arnon and coworkers in 1940, using radioactive phosphorus, traced the metabolism of inorganic phosphates in the leaves and fruits of the tomato plant. Leaves and slices of the tomato fruit, 2 to 4 millimeters thick, were placed on paraffined paper on top of X-ray films wrapped in black paper. A heavy glass plate held the samples close to the film. The developed films showed that radiophosphorus was accumulated in the seeds of green fruit, whereas only traces were found in ripe fruit and no concentration was found in ripe seeds. Also the conducting system of the leaves accumulated a large amount of radiophosphorus.

Pecher in 1942 used autoradiographs to show the accumulation of phosphorus 32 in the skeleton and soft tissues and of strontium 90 in the skeleton of whole mice. Thick slices cut from frozen animals were placed on film covered with cellophane, and the whole set-up kept in the refrigerator during the exposure.

Reinhardt in 1942 used autoradiography to determine the completeness of thyroidectomy. Tissue masses from animals which supposedly had had their thyroids removed and had been injected with radioiodine were

[2] Hine, Carroll L. *and* Brownell, Gordon L., *ed.* New York 10: Academic Press, 1956.

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placed on filter paper, covered with cellophane, rolled flat, and placed on X-ray film. Although none of the animals showed any remnants of the thyroid tissue upon visual examination, 50 percent of the animals showed, by the action of radioiodine in the autograph, the incompleteness of the thyroidectomy.

Following World War II, many new isotopes were added to those which scientists could use in their investigations. There seems to be no limit to how many new uses can be found for these isotopes, especially in industry and research. Metal castings and welds can be inspected for possible flaws not otherwise detectable. The intensity of a beam of rays passing through sheets of paper, plastics, glass, or metals can be used to gage the thickness of the sheet. A picture painted or printed with sufficiently long-lived radioactive ink can be reproduced as many times as desired by placing it in contact with photographic paper and then developing the image. A badge containing photographic film can be used to measure the amount of radiation exposure. If on a person at the time of exposure, it measures the individual's exposure. The fundamental principles underlying many of these applications can be clarified by means of demonstrations or laboratory exercises (see pp. 40 and 41).

How to Make Autoradiographs

Several variables affect the quality of any autoradiograph. The film must be adequately but not overly exposed and the silhouette produced on the film must reveal faithfully the location of the radioactive materials present in the object being autoradiographed. Several variables affect exposure time. The energy of the radiation emitted by the isotope and the rate at which it enters the emulsion on the film must both be considered. It has been estimated that 1 to 2 million beta particles striking 1 square centimeter of no-screen X-ray film will give minimum exposure; and a satisfactory autoradiograph calls for approximately 1½ million particles per square centimeter. (No-screen film differs from the usual X-ray film, which, in use, is backed up with a fluorescent screen so that the film image will be intensified by the additional exposure caused when the X-rays make the screen fluoresce.)

The film itself introduces certain variables because emulsions differ in the number of silver atoms per square centimeter of film, how the atoms are distributed, how near they are to the surface, and the chemical properties of the compounds in which the silver atoms are included. Obtaining a true silhouette depends on washing away none of the reduced silver atoms during the development process and leaving none of the oxidized silver atoms in the emulsion.

The silhouette produced on the film will be a faithful reproduction of the distribution of radioactive material in the sample only when the film is placed very close to the source of the radiation. Perhaps this will be easier to understand if you imagine yourself trying to locate a baseball batter simply by studying the balls he has hit. The closer you are to him, the more balls you would be able to see and the more accurately you would be able to tell where he is standing. If a thick section of the sample being radiographed is used, the film cannot be as close to the back side of the section as it is to the front side. Unless the material absorbs the radiation from deep within the sample, the autoradiograph will be "out of focus" because the radiation falling on the film will have come from several different angles. When heavy weights are used to maintain closer contact between the emitting material and the film, too much pressure must be avoided because X-ray films can be exposed by a pressure effect and thus produce a misleading autoradiograph.

For general work with alpha and beta emitters the films most commonly used are no-screen and dental X-ray films. Lantern slide plates are sometimes used, but are slower. Microscope slides coated with various emulsions are available for mounting sections directly on the emulsion. Ordinary high-speed camera film can also be used but it must be handled under complete darkness and requires exposure times from 20 to 50 percent longer than the no-screen X-ray film. The demonstration activities to be described later in this publication include various adaptations which reduce the autoradiographic procedure to a rather simple yet effective method for keeping track of nuclear radiation.

Tracking Radiation With the Geiger Counter

In the classroom, there are advantages in combining autoradiography as a means of

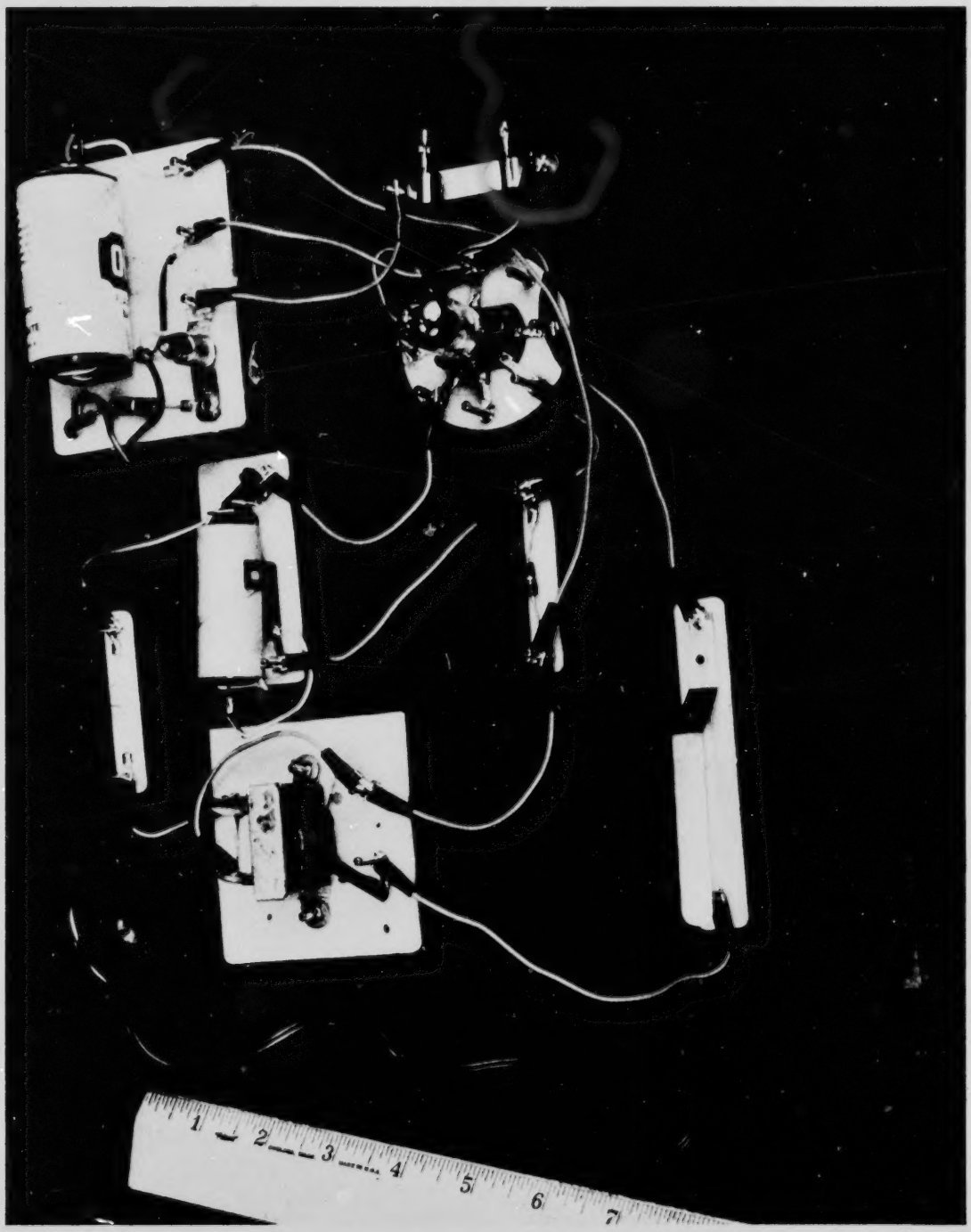


FIGURE 10.—Pegboard-model Geiger counter assembled by clothes-pin type connectors. Telegraph sending key makes and breaks current from battery pack, causing transformer to charge condenser, which maintains 300-volt charge on GM tube. Ionizing radiations entering tube release electrons to amplifying tube circuit sufficient to cause a click in earphone. (Circuit could be improved by moving GM tube near edge of baseboard and attaching rule or scale, thus placing sample to be counted at measured distance from tube. Stopwatch needed to tally count.)

keeping track of nuclear radiation with the use of a Geiger counter. Intelligent use of a Geiger counter, however, requires an understanding of the basic principles of its operation. One of the most effective ways to acquire an understanding of these basic principles is to put together some of the simple circuits described in science teachers' magazines or the semipopular electronics journals. For example, Orin Rodewald reports that one of his students in the Muskegon, Mich., High School achieved very satisfying results by following the suggestions which appear in an electronics magazine.[3] This circuit calls for a 300-volt Geiger tube, 1½-volt flashlight battery, a CK722 transistor, and other low-cost components. The accompanying photographs show two commercially available kits which suggest the types of "do-it-yourself" Geiger counters currently available.

Classroom models of Geiger counters designed especially for instructional purposes are available. The addition of such an instrument to the science laboratory equipment will make possible many interesting and effective teaching activities.

In connection with its efforts to provide the Nation with a group of people who are able to serve as radiation monitors in time of national emergency, the Office of Civil and Defense Mobilization cooperates with school people by making available the Geiger counters used to train radiation monitors. Not only are these instruments extremely rugged, but they are readily adaptable to classroom use. Several photographs throughout this publication show how the civil defense Geiger counter can be used in the classroom.

In many cases, teachers must learn to use a Geiger counter. The instrument guide sheet which follows may help accomplish this purpose.

Geiger Counter Instrument Guide Sheet

The heart of this instrument is a Geiger tube—a glass or metal cylinder which may be from a few inches to several feet in length and with a diameter less than that of a pencil to an inch or more. (Geiger counters designed for the detection of alpha radiation must have an extremely thin window. Mica usually is used for this purpose.) Two or three wires enclosed in an insulating and protective cable connect the Geiger tube to something that will change each count to clicks in an earphone, activate

[3] *Popular Electronics*, 4:90–93, June 1956.

FIGURE 11. Commercial kit in assembled and unassembled form. The transformer relies upon an air gap to charge the condenser.

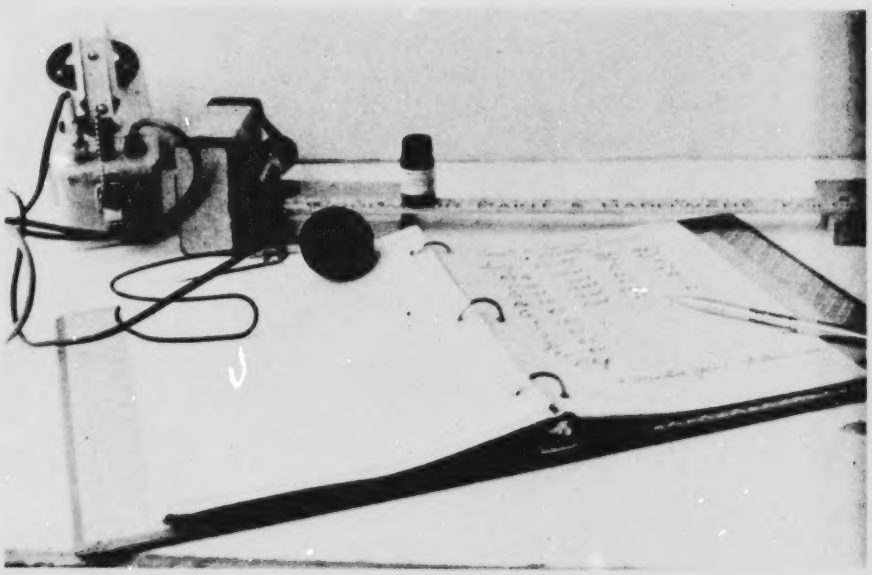


FIGURE 12.—Civil defense Geiger counter: probe taped to a wooden block fastened to a yardstick. Purpose: to estimate number of gamma rays from bottle of 10 microcuries of iodine 131.

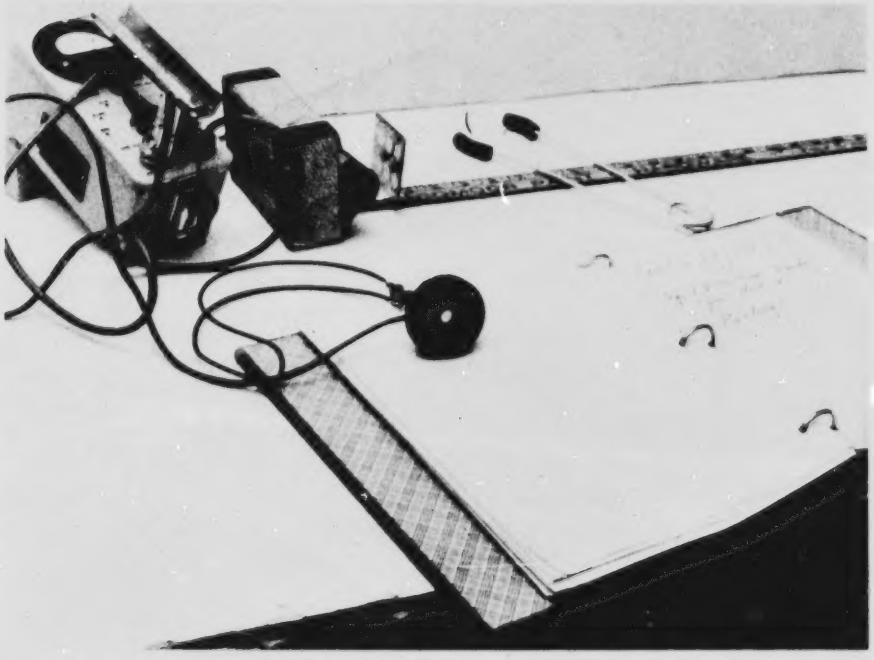


FIGURE 13.—Civil defense Geiger counter for observing the count from a test card on which are paper disks soaked with equal quantities of two isotopes of different half-lives.

a meter, or operate a mechanical counter. Portable instruments, more commonly used in monitoring radiation for radiological defense and other purposes, show a reading on a scale rather than activating ear phones, lights, or mechanical counters. The tube of a Geiger counter is usually mounted in a protective metal cylinder called a probe. The power source in portable models is made up of two or more 45- and 1.5-volt batteries. Newly developed transistorized Geiger counters use 1.5-volt batteries only. Usually the power source and indicating mechanism are put in the same container.

The Geiger counter will respond to any kind of radiation that has enough energy to dislodge electrons from the wall or window of the tube and ionize the gas molecules within the tube. The newly formed electrons pick up additional energy causing further ionization, and thereby forming more electrons in a continuous process. Finally, a large number of electrons is collected by a strongly positively charged wire in the center of the tube. Upon reaching the wire, the negative ions give up enough electrons to form a pulse of current in an outside circuit leading to an amplifier. The amplifier, in turn, operates a blinking light, headphones, or a mechanical counter. In some models, an ammeter reads the amount of the amplified current which, in turn, can be converted into equivalent counts per minute.

Questions and Answers

1. *Q. What happens when I turn the Range Control switch to the 1X position?*
   A. A positive charge of about 1,000 volts is applied to the collecting wire in the Geiger tube and the batteries begin to deliver voltage to the amplifying circuit.
2. *Q. Actually, what makes the needle move across the scale?*
   A. When any kind of ionizing particle enters the Geiger tube, a surge of electrical current flows through a small coil of wire that is in a magnetic field. The newly created magnetism within the coil is opposed by another magnetic field which causes the coil to turn. The indicating needle is fastened to this coil.
3. *Q. What fundamental principle is applied in the design of the Geiger counter?*
   A. There are several principles involved, but the most important one is that unattached electrons and/or gamma rays whizzing past gas molecules may ionize the molecules by removing one or more electrons or by being taken up by neutral atoms.
4. *Q. Will the Geiger counter wear out?*
   A. Yes, for two reasons among others. First, the batteries have a limited life; and second, the gas molecules within certain types of tubes can form only so many ions. Halogen tubes, however, are said to have an unlimited life.
5. *Q. Will each beta or gamma ray that impinges on the walls of the probe trigger a count?*
   A. If a beta particle has enough energy to dislodge electrons from the walls of the Geiger tube, it is almost sure to trigger a count. Not much more than one percent of the gamma radiation that passes through the tube, however, will interact with the molecules of the tube wall or of the gas in such a way as to produce a count.
6. *Q. Does each click of the counter mean that a beta or gamma ray has entered the counter?*
   A. No, the count could have been caused by a cosmic ray.
7. *Q. How can I tell whether a count was caused by a beta particle or a gamma ray?*
   A. Close the shield on the probe. Beta particles can't penetrate the thick metal shield.
8. *Q. When the shield is open, how can I tell a beta ray count from a gamma ray?*
   A. You can't. Nor can you be sure it wasn't a cosmic ray.
9. *Q. Provided the switch is on, is the Geiger counter always ready to count a beta or gamma ray?*
   A. Not quite. Most counters need a split second to register one count and recover for the next. For example, a ray that enters one type of counter less than 0.001 second after one that is being registered will escape recognition.
10. *Q. If I know how long it takes my counter to register a count and recover, can I correct readings accordingly?*
    A. Yes, use the following formula:

$$n_t = \frac{n_o}{1 - n_o t_r}$$

n_t—true count
n_o—observed count
t_r—resolving time

For example, in the situation in Question 9, a reading of 100 counts per second would mean that the tube would have been "busy" 100 times during the second for a total time of 0.1 sec. During this time it would have missed about 11 counts.

11. *Q. What happens if I turn the switch to the 10X position?*
    A. Ten pulses are piled up on a condenser and only a proportional amount of current flows through the meter.
12. *Q. How about the 100X position?*
    A. Same story except this condenser holds 100 ordinary pulses.
13. *Q. What does it mean if my counter reads 0.04 mr/hr on the 10X scale but doesn't read 0.4 mr/hr on the 1X scale?*
    A. There are several possibilities. Perhaps one of the condensers is losing its original characteristics.

14. *Q. Can I still use my counter?*
    A. Yes. You must, however, calibrate each scale separately.
15. *Q. How do I calibrate a Geiger counter?*
    A. By recording some readings when you know or can calculate what it should read. A graph of these values will allow you to change any meter reading to the correct value.
16. *Q. How can I tell or calculate what my meter should read?*
    A. Obtain a source of known intensity and use the inverse square law.
17. *Q. What is the inverse square law?*
    A. The intensity of the radiation received from a point source (assuming none is lost on the way) decreases as the square of the distance increases.
18. *Q. Give me an example.*
    A. If you move 4 times as far from a source, you will receive $\frac{1}{16}$ as much radiation.
19. *Q. Where can I get a source of known strength?*
    A. Accurately calibrated sources are hard to obtain. Check with your local civil defense office or university or industrial research radioisotope laboratory.
20. *Q. What does a source look like?*
    A. There are several kinds. Some are small metal capsules shaped like pencil erasers, some are like metal buttons or slugs, and some are liquids or evaporated residues in small bottles. In any case, the supplier gives you the strength in curies at the time the source was made.
21. *Q. Why does the time make a difference?*
    A. Because after each ray or particle is emitted there remain fewer rays or particles to be emitted. This process is called radioactive decay.
22. *Q. What do you mean "strength in curies?"*
    A. The curie is the unit for measuring radioactivity. One curie is equivalent to 3.7×10^{10} disintegrations per second; about the number of disintegrations per second from one gram of radium.
23. *Q. Aren't there smaller units?*
    A. Yes, millicuries and microcuries, the first equivalent to 3.7×10^{7} counts per second and the latter 3.7×10^{4}.
24. *Q. About what should my counter read if I hold it 1 foot from a 10-millicurie source?*
    A. This depends on the kind and energy of the radiation the source produces.
25. *Q. How can I know that?*
    A. Each element or isotope emits characteristic radiation. For example, P^{32} emits beta rays only, I^{131} emits both beta and gamma rays, and U^{238} emits alpha particles. This information is in handbooks and reference books.
26. *Q. Do all radioactive materials decay at the same rate?*
    A. No. This too depends on the element or isotope involved. For example, the half-life of P^{32} is 14.3 days; for I^{131} it is 8 days, and for Co^{60} it is 5.3 years.
27. *Q. What does "half-life" mean?*
    A. The time it takes for a source to decay to one-half its original strength.
28. *Q. Why use such an awkward unit as that to express the decay rate of radioactive materials?*
    A. It's less awkward than any other unit when you realize that any atom is as likely to decay as any other atom of the same element or isotope. The life of a radioactive atom is not at all the same idea as the life of a plant or animal. Among living things we know that the older one of them becomes, the more likely it is to "decay." Physicists have no way to tell which atom in a group of atoms will be the next one to decay.
29. *Q. Does this mean that a 10-microcurie source of P^{32} would be less than one of 5 microcuries about 15 days after it had been prepared?*
    A. Yes.
30. *Q. Coming back to Question 24: Should my Geiger counter read 1.35×10^{4} counts per second if I use a 10-microcurie source of P^{32} that is 15 days old?*
    A. Try it and see. But remember that you will have to collect all the beta rays being emitted.
31. *Q. How do I do that?*
    A. You can't—a Geiger counter isn't built that way.
32. *Q. I still want an answer to Question 24.*
    A. The answer depends on several things. Some of the beta particles spend their energy ionizing air molecules along the way and never reach or enter the window of your counter. If the P^{32} is a point source, its beta particles fly out evenly in all directions through a sphere that becomes larger and larger as you move from the source. One foot from the source, for example, the particles would be distributed more or less evenly over a sphere with an area of about 290 square inches. If the window of your counter is only about 1½ square inches in area, it should collect only about 1/200 of the beta rays being emitted.
33. *Q. You mean my question can't be answered.*
    A. At least we can say that it won't be more than 68 counts per second.
34. *Q. That's not much help. Let's put it this way: If I were to have to run through a no-man's land where rifle slugs are whizzing by, bazooka rockets whistling about, and hand grenades being tossed around, I would like to know my chances of getting through alive.*
    A. Right. And in your no-man's land, as in a radioactive field, it would be risky business to go in and actually count the things that worry you.
35. *Q. Even trying to judge how dangerous the place is by going in there for a brief sampling also would be too dangerous, wouldn't it?*
    A. You're right; so let's try the indirect approach. If you know how much noise a given number of rifle shots, rocket, and grenade explosions make, you could estimate the danger in the no-man's land by safely standing on the sidelines and just listening.

36. *Q. Let's come back to gamma, beta, and alpha particles: we can't hear them.*
    A. No, but we do know how to get them to develop electrical currents. Put your Geiger counter in some radiation field where you know how many beta and gamma rays are whizzing by, record the readings on your meter, and from then on you can exchange your readings for estimates of the numbers of gamma and beta rays actually present.
37. *Q. Give me an example.*
    A. Suppose you have a 10-millicurie source of Co^{60}. Handbooks show that 1 millicurie of this isotope produces 1.59 milliroentgens per hour at 1-yard distance. Your 10-millicurie source would produce 15.9 mr/hr at 1-yard distance. Using the inverse square law you can calculate the values expected at other distances. You can then exchange whatever your meter reads for what you know it should read.
38. *Q. Wait a minute. Why did you switch from curies and disintegrations per second to milliroentgens per hour?*
    A. First, that is the way the meters on some counters read. This is so because civil defense workers and research scientists need to know the effects of gamma and beta radiation. Since these effects are almost identical to those of X-rays, the X-ray measuring unit, the roentgen, is used.
39. *Q. But what would the reading 15.9 mr/hr really mean?*
    A. A roentgen is defined as the quantity of gamma or X-radiation needed to produce a specific number of ions in air. If a chest X-ray calls for an exposure of 1 roentgen, the technician may adjust the machine to deliver 7,200 r/hr and give a ½-second exposure. A civil defense worker who had to stay in a radiation area of 15.9 mr/hr intensity would accumulate .159 roentgen if he worked there for 10 hours.
40. *Q. Now suppose that my counter reads 32 mr/hr when I hold it 1 yard from a 20-millicurie source of Co^{60}. What does this mean?*
    A. First, we know that there are about 74,000,000 disintegrations per second in a 20-millicurie source of Co^{60}. Second, the formula

$$\text{mr/hr} = \frac{1.59 \text{ mc. of } Co^{60}}{(\text{distance in yds})^2}$$

    tells us that a 20-millicurie source should produce 31.8 mr/hr at a distance of 1 yard. Combining these two facts, we can say that of all the gamma rays that shoot from the Co^{60}, at a distance of 1 yard they are dense enough to cause a radiation intensity of 31.8 mr/hr.
41. *Q. But my meter reads 32 mr/hr. Where did the other 0.2 mr/hr come from?*
    A. This may be caused by a number of things. Perhaps your counter simply reads too high. It could be picking up stray radiation. Perhaps the source was actually stronger than the label indicated.
42. *Q. Is there any way to adjust my counter to make it read what it is supposed to?*
    A. Yes. See your Instruction Manual.
43. *Q. If I want to check something that may or may not be radioactive, how do I know that my counter is working?*
    A. Hold the probe close to a luminous watch dial. There is also a beta radiation source under the nameplate on some Geiger counters.
44. *Q. What do I do if my counter isn't working?*
    A. Follow the suggestions under Preventive and Corrective Maintenance in your Instruction Manual. Remember, however, that this is a poor instrument to use to learn how to be an electronics expert.

Understanding Electronic Circuits

Electronic circuits are difficult for some students to understand; and students progress slowly in the use of any electronic instrument until its circuits *are* understood. Charles A. Culver provides some material [4] that has been adapted to a teaching aid that holds promise of helping students understand electronic circuits. The aid follows:

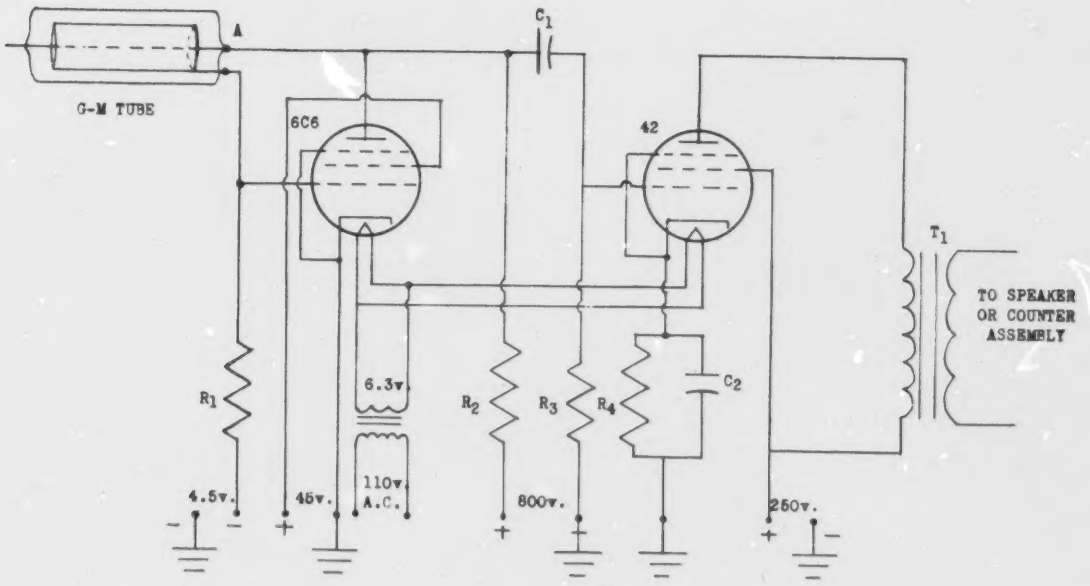
The first time one sees a diagram of an electronic circuit he is likely to be frightened by how complicated it seems. Even an electronics engineer might feel the same way upon seeing for the first time a woman's kitchen recipe or a set of blueprints for making a rose trellis or even the plans for a model airplane. Each of these is simply a shorthand way of showing how something is put together. As soon as you know what each symbol means it is quite easy to see how the parts go together.

To gain practice in understanding an electronic circuit, let's look at a typical example of the kind of wiring and the parts needed to make a Geiger counter tell us whether it is near a source of beta, gamma, or other radiation to which it can respond (see fig. 14).

Before we try to decipher what this all means, let's recall briefly what a Geiger counter does. In general, it simply picks up very tiny bits of electricity and then multiplies each into a large enough package to cause clicks in earphones or a loudspeaker.

Now let's look at the Geiger counter circuit, a part at a time. Try to follow some imaginary electrons from the junction marked "A" through the circuit and back to the starting point. Do you see how they could be "pulled" by the battery down the circuit, through the battery, through the ground, and back up to the Geiger tube? Do you also see that they would have to pass through the two resistances, R_1 and R_2 and jump the gap between the central wire and surrounding cylinder in the Geiger tube? It is this gap that is the heart of the Geiger counter. The battery places a charge on the central wire that is just about, but not quite, strong enough to allow electrons to jump the

[4] In an article, "Construction and Use of a Geiger-Mueller Counter Assembly," *Science Counselor*, 12:3:87-89; 104, September 1949.



R_1 - 2 to 10 x 10^6 ohms, 1 watt

R_2 - 2 x 10^6 ohms, 2 watts

R_3 - 0.5 x 10^6 ohms, 1/2 watt

R_4 - 400 ohms, 2 watts

C_1 - 50 to 100 mmf, high voltage

C_2 - 10 to 25 mf at 25 to 50 volts

V - DC counter threshold $\neq$ 100 v.

T_1 - Output transformer

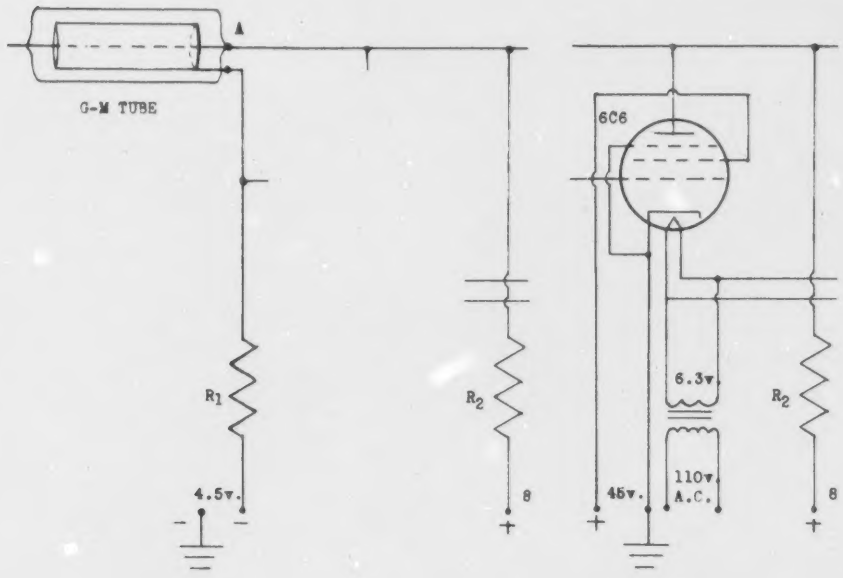


FIGURE 14.—The complete circuit of a Geiger counter can be more easily studied if broken down into portions.

gap. When any charged particle or ionizing ray enters the tube, a whole surge of electrons will jump the gap.

When this surge of electrons begins to flow through the Geiger tube, why doesn't it continue? The answer is that the electrical discharge through the tube is terminated by action of the quenching gas—either organic vapor or halogen gas—in the tube. The exact manner in which the quenching action is performed is not known.

Now let's look at the 6C6 tube in figure 14. When the current from the 6.3-volt source heats the tube's filament and electrons are boiled off, do you see why they don't jump directly to the positive plate? Do you see how the negative grids would repel them? Do you also see how the negative grids would become less of a barrier while the surge of current discussed in the previous paragraph was flowing? On this basis, the 6C6 tube serves as a valve that allows a larger pulse of electrons to flow through the circuit each time one of the smaller pulses comes from the Geiger tube. Not only do these larger pulses help quench the flow of electrons through the tube but they can also be fed into an amplifier tube, eventually to operate a loudspeaker or a set of earphones.

These larger surges of current from the 6C6 tube pass through the condenser C_1 and on to the grid of the 42 tube. Do you see how this grid can now serve as a gate or valve for even larger currents between the filament and plate of the 42 tube? In this case a 250-volt source is forcing electrons through the tube and, once the negative grid in the tube no longer blocks their flow, they will pass through the coil of a transformer and be stepped up enough to operate a loudspeaker or some kind of counting machine.

With this much of a start, see whether you can trace the various paths electrons might follow throughout the Geiger counter circuit. Keep in mind what would be most likely to happen to them as they encounter each resistance, condenser, filament, grid, or other part.

Adapting Geiger Counters

Continued use and increasing familiarity will allow teachers to adapt Geiger counters to whatever needs they encounter in their own classrooms. For example, Clifford Malone, a teacher in the West Side Junior High School at Groton, Conn., has converted the civil defense Geiger counter to produce audible and visual signals for group demonstrations. He disconnected the earphones from the cord leading to them and attached the cord to the microphone jack and plug of a record player, tape recorder, public address system, or movie projector. With the tape recorder, for example, in recording position, the glow bulb gave a strong flash each time the Geiger counter clicked.

Isotopic Effects on Films and Geiger Counters

This is an effective exercise in teaching students to handle small quantities of radioactive materials and to acquaint them with the characteristics of their radiation. Get freshly calibrated 1-, 10-, or 50-microcurie quantities of such isotopes as phosphorus 32, iodine 131, cobalt 60, sodium 22, calcium 45, sulfur 35, or other generally licensed isotopes. All isotopes should be in solution and diluted to uniform activity per milliliter solution. If they are delivered in dry form, use a dilution of one microcurie per milliliter solution. Most teachers will have to be satisfied with an approximation of this factor.

Radioactive Materials From Precalibrated Sources

If the available isotopes are of different half-lives and are not freshly calibrated, simplify the calculations required to equalize quantities of radioactive materials by using the table[5] below. Two problems and their solutions are given after the table.

TABLE 1.—*Data to simplify calculations for equalizing quantities of radioactive materials*

Time expressed as percent of half-life	*Percent remaining*	*Reciprocal*
0. 05	0. 965	1. 035
. 10	. 933	1. 072
. 15	. 900	1. 109
. 20	. 870	1. 149
. 25	. 841	1. 188
. 30	. 811	1. 231
. 35	. 784	1. 275
. 40	. 759	1. 318
. 45	. 732	1. 365
. 50	. 706	1. 415
. 55	. 684	1. 464
. 60	. 660	1. 515
. 65	. 637	1. 570
. 70	. 616	1. 624
. 75	. 595	1. 682
. 80	. 574	1. 741
. 85	. 554	1. 802
. 90	. 535	1. 866
. 95	. 516	1. 933
1. 00	. 500	2. 000
1. 2	. 435	2. 298

[5] Set up by G. H. Rees.

TABLE 1.—*Data to simplify calculations for equalizing quantities of radioactive materials*—Continued

Time expressed as percent of half-life	*Percent remaining*	*Reciprocal*
1. 4	0. 379	2. 641
1. 6	. 330	3. 034
1. 8	. 287	3. 490
2. 0	. 250	4. 000
2. 25	. 210	4. 759
2. 50	. 177	5. 641
2. 75	. 148	6. 753
3. 0	. 125	8. 000
3. 5	. 088	11. 36
4. 0	. 062	16. 00

Problem: The half-life of Na^{24} is 15 hours. A 100-microcurie sample will have what activity after 3 hours?

Solution: 3 hours = 3/15 or 0.2 half-life. Opposite 0.2 in the first column, find the percent remaining = 0.87. The activity of the sample is 100 × 0.87 = 87 microcuries.

Problem: A sample of Na^{24} has a count rate of 1,000 counts per minute at 3 p. m. What was its count rate at 9 a. m. the same day?

Solution: The time elapsed was 6 hours or 6/15=0.4 half-life. Opposite 0.4 in the first column, find 1.318 in the reciprocal column. (Since we are figuring back to an earlier time, the factor must be larger than 1.0.) The count rate is 1,000 × 1.318 = 1,318 counts per minute.

As soon as the uniform activity solutions are ready, prepare low-level dry sources of each solution by soaking small paper disks in the solutions. Dry each disk, paste it to a larger labeled cardboard, and then wrap the cardboard with transparent plastic. It is well to prepare several disks from each solution at the same time. Each disk can be placed separately at an appropriate distance from the Geiger counter tube to observe its effects on the Geiger counter.

To compare the effects of the various isotopes on film, mount several different kinds of disks on a test card and then wrap the test card with transparent plastic. A piece of photographic film, cut to just cover the test card, can then be placed over the test card, the preparation wrapped with lightproof paper, placed between the pages of a book to provide adequate contact pressure, and left for an appropriate exposure time.

There are advantages to be gained from using paper disks from an ordinary punch for notebook paper. The disks are small and can be mounted on a 35-millimeter card so that the individual pieces of film, after exposure and development, can be framed with ordinary 2″ x 2″ slide binders for classroom projection purposes.

Additional information about this exercise can be obtained from the captions of the accompanying photographs (figs. 15 and 16).

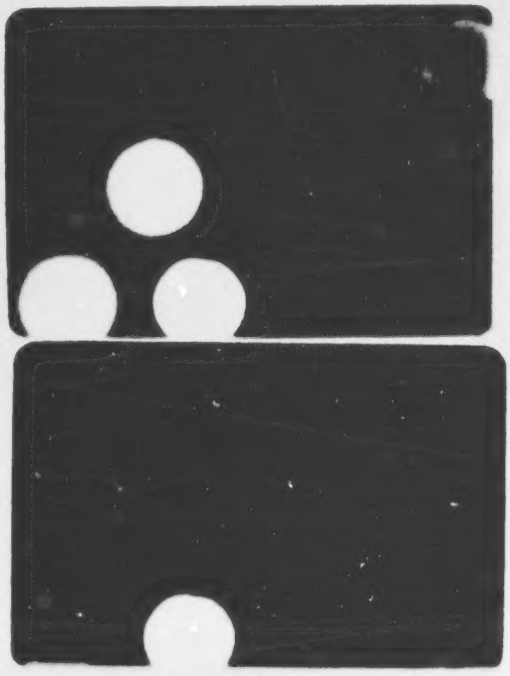


FIGURE 15.—Paper disks were soaked in 1 microcurie per milliliter solutions of 9 different isotopes. After drying, the individual disks were glued to a 35-millimeter card, wrapped with transparent plastic, and placed in contact with no-screen X-ray film for 11 hours. The top print shows the effect on the film 4 days after the isotopes were calibrated. The bottom print shows the effect of the same test card on a new piece of film 45 days after calibration of the isotopes. Development procedures were approximately equal in both cases to insure equal film densities. The 9 isotopes from top left to bottom right were calcium 45, chromium 51, cobalt 60, iodine 131, phosphorus 32, rubidium 86, sodium 22, sulfur 35, and zinc 65. (NOTE: There are reasons to believe that the chromium 51 used in this exercise was not accurately calibrated.)

How Radiation Passes Through Materials

Paper disks and test cards similar to those in the previous exercise are useful in the observation of the shielding effects which various

FIGURE 16.—Small squares of blotting paper were soaked in 1 microcurie per milliliter solutions of 9 isotopes. The squares were dried, pasted to a $2\frac{1}{4}'' \times 2\frac{1}{4}''$ test card, and wrapped with transparent plastic. The test card, in turn, was mounted over the film opening in a box camera. The camera was loaded with Kodak Tri-X film and the various frames rolled by for increasing exposure times. The top print is from a 60-hour exposure and the bottom print from a 13-hour exposure. Beginning at the bottom right and working up around and back down are the isotopes, iodine 131, chromium 51, cobalt 60, calcium 45, sodium 22, phosphorus 32, rubidium 86, sulfur 35, and zinc 65.

materials have on nuclear radiation. Known thicknesses of various materials can be simply inserted between the test cards and a Geiger counter tube. The lead foil that comes in dental film packs is approximately 0.06 millimeter thick and weighs 0.07 gram per square centimeter. Ordinary lightweight kitchen aluminum foil is approximately 0.0007 inch thick and runs about 0.0046 gram per square centimeter. Plumber's lead comes in sheets approximately one-sixteenth of an inch thick and runs 4 pounds per square foot.

The accompanying photographs show how photographic film can be used to observe the shielding effects of various materials (see figs. 17 and 18).

Nuclear radiation's loss of energy as it passes through the air, becomes complicated by the inverse square manner in which its density is reduced as it travels farther from the source. Using a Geiger counter under a partial vacuum becomes something of a problem, but one which an ingenious person may be able to solve. The accompanying photographs show how film can be used to observe the effects of increasing lengths of air paths. This procedure may yield very interesting results when repeated under a partial vacuum and the effects compared with those obtained under ordinary conditions.

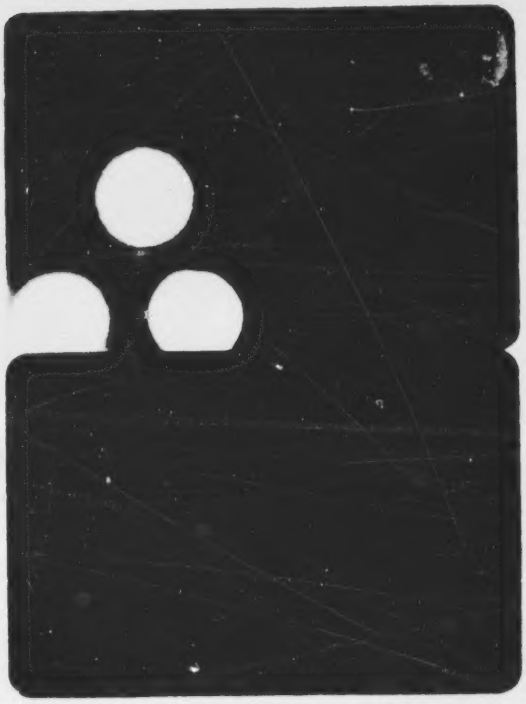


FIGURE 17.—A test card similar to that used in figure 15 separated from no-screen X-ray film by 13 sheets of lead foil. The top print shows the effect of a test card without lead shielding. The bottom print shows the effect of 16-hour exposure with three sheets of lead foil between the test card and the film. The high energy beta particles from the phosphorus 32, rubidium 86, and sodium 22 were able to penetrate the lead foil. This shows clearly, however, that the beta particles from these isotopes have a range of energies with only the very highest energy particles getting through the lead foil.

Atomic and Subatomic Dimensions

To gain a realistic and working knowledge of the radiation which accompanies disintegration of unstable nuclei, one must expand his ability to grasp exceedingly small and exceedingly large dimensions. Wolfgang Pauli [6] shows how easily our concept of dimensions can influence our understanding of things in our environment.

To try to visualize some of these things, imagine a person standing on the sand at the edge of a pond, then shrinking to about 1/250 of an inch. As he shrinks, the treetops fade from sight, the pond becomes a sea, the sand becomes a plain of boulders, each over a thousand feet high—and he is standing on one of them. He tries to walk, but the air would seem thick, almost fluid, as if he were walking in water. At the edge of his boulder, he tries to drop a stone to test the depth of the pit but the stone floats in the air until a gust whisks it away. He may find that he stops breathing, because he is absorbing all the oxygen he needs for his reduced volume through his skin. But he becomes intolerably thirsty, since his increased relative surface loses moisture at many times the normal rate. Actually, he would become a desiccated mummy, but we may compromise by assuming that he is merely thirsty. Reasoning from the behavior of the stone, he figures he too can float down to the water to get a drink—and he does. But try as he will, he cannot break through the tough surface membrane of the water, on which he slips and slides as on elastic ice. So he comes ashore again and finds a mountainous dewdrop which he tries to pierce with a straw. If he succeeds in doing so, the water might at once suck the straw and the man into its crystal interior, holding him helplessly captive, too weak to cope with molecular forces.

[6] In his *World of Life*, p. 25. New York: Houghton Mifflin Co., 1946.

FIGURE 18.—Paper disks soaked in sulfur 35, calcium 45, and phosphorus 32 represented low, medium, and high energy beta-emitting isotopes. For the top print, the paper disks were allowed to project over the edge of a pack of lead foils which separated the paper disks from a piece of film. The film was exposed for 23½ hours. The 1 microcurie per milliliter solutions of the isotopes were 30 days old. In the bottom print, the paper disks were separated from the film by 10 sheets of aluminum foil and given a 12-hour exposure.

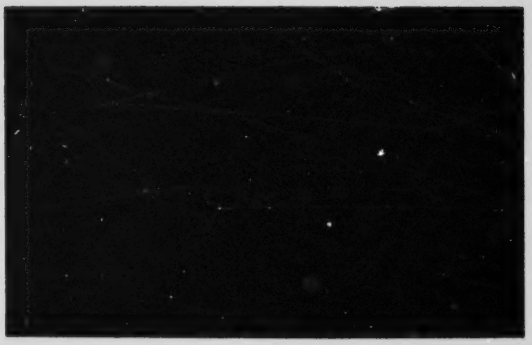


FIGURE 19.—A small ball of cotton fastened to a toothpick was dipped in phosphorus 32 and mounted on insulating wall-board in the bottom of a shoebox. Pieces of film behind sheets of lead containing three holes were mounted at increasing distances from the phosphorus 32. The two prints show the effects of the beta particles on the film at distances of 1 inch and 4 inches through a 48-hour exposure.

It was only by developing a realistic concept of the dimensions of atoms and subatomic particles that physicists were able to develop a concept of atoms. A good example is found in the work of E. Rutherford, in 1906. Two of his students, Geiger and Marsden, tried to determine the number of alpha particles expelled from one gram of radium. While experimenting, they were puzzled to see "some of the alpha particles can be turned within a layer of 6×10^{-5} centimeters of gold to an angle of 90 degrees, and even more." Familiar as he was with the high velocity and mass of alpha particles, to Rutherford this was "about as credible as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you." This led him to abandon the idea that the particles making up an atom were evenly

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distributed throughout the atom. He came to see the atom as containing "a central charge distributed through a very small volume." Thus we can understand that the concept of an atomic nucleus reflects Rutherford's ability to think in atomic particle dimensions. Furthermore, many of the phenomema of nuclear science are totally confusing unless students understand the relation between actual particles and space in the structure of material.

How can we explain to the student that gamma rays, beta particles, or other atomic radiation can go through what is apparently solid stuff and not, necessarily, leave a hole? First, what do we mean by "leaving a hole?" For example, to make a hole in a flock of flying geese, must a bullet actually hit a goose? Let's assume that is what we mean. All we have to do is convince our student that the atoms which make up his body are actually flocks of very small geese flying around in very, very large flocks. For an average atom, about one ten-trillionth of it is actually material and the rest is simply space bounded by rapidly moving particles. In other words, for each goose in a flock, there would be room for about 9,999,999,999,999 other geese. This means that if we were to shoot a goose-sized bullet at the exact center of such a flock of geese we would have one chance in about 10 trillion of hitting a goose.

We must recognize, however, that many atomic bullets do not pass through the materials they encounter just as all the hunter's bullets don't miss the flying geese. Atomic bullets that are "near misses" can dislodge electrons from the outer orbits of atoms, losing a little energy in the process. The hunter's bullets can knock feathers from a goose without actually penetrating the goose's body. The goose that has lost some feathers will, of course, feel and behave differently from one that has not had such a close call. Atoms that have lost electrons are called "ions" and they, too, behave in a manner different from that of normal atoms.

Laboratory exercises of the type discussed in this chapter help one realize atomic and subatomic dimensions. Consider, for example, figure 15. One can see how the high energy beta particles from phosphorus 32 range far from the paper disk, causing a fuzzy spot to appear on the film. Low energy beta particles, such as those from sulfur 35, either fail to get out of the paper disk or fail to penetrate the transparent film between the paper disk and the film. In no case do they range far into the emulsion of the film.

Ionizing Effects of Nuclear Radiation

To handle radioactive materials intelligently, confidently, effectively, and safely, we must forever keep in mind that the radiation which they produce is capable of ionizing atoms. Chemists, especially biochemists, realize that ionized atoms and ionized portions of molecules are quite different from nonionized materials. Molecules which exist in one form in the body may exist in an entirely different form if they are broken up by ionizing radiation and allowed to recombine. If the newly formed compounds are physiologically significant and exist in large enough concentrations, the radiated individual will show symptoms of radiation sickness. The nature of these symptoms will depend upon what body tissues and organs have been affected, how seriously they have been affected, and the function they perform in the total body process. Since nuclear radiation can demolish or rearrange the structure of almost any molecule, to the extent that future physiological processes depend on gene-controlled hormone or enzyme production, the effects of radiation on any individual may show some time after exposure to it. Repetitive doses may show more marked accumulated effects on some physiological processes than on others.

The widely publicized genetic effects of nuclear radiation carry additional importance. To the extent to which individual genes and/or complete chromosomes within the germ plasm are demolished, damaged, or rearranged, variations in the functional or anatomical traits carried by these genes or chromosomes will occur in offspring inheriting the changed gene or chromosome.

It is very difficult to predict the quantity of abnormal molecules that will be produced as a result of ionizing radiation or to predict physiological effects of the newly formed materials. At the time of preparing this publication, there is widespread disagreement among scientists on these matters. When faced with this situation a teacher sometimes can meet his responsibilities

to his students by helping them analyze data available from experimental studies. Two examples of how this may be done follow:

The first is an account of Johanna Blumel's research on the action of radioactive phosphorus in Drosophila. It is followed by an interpretation-of-data study exercise. The second experimental study, reported here in tabular form, compares the number of offspring produced by female rabbits mated to control, versus irradiated, males. It, too, is followed by an interpretation-of-data study exercise for students.

How large doses of beta radiation affect fruit fly offspring.—The purpose of Johanna Blumel's study was to determine what happens to the offspring of fruit flies that have been given large doses of beta radiation. She found some most unusual and interesting mutations among the second generation.

Pairs of mature flies from stock bottles were placed in shell vials containing a radioactive medium. This culture medium had been prepared by adding approximately 3.2 milliliters of radioactive H_3PO_4 (containing about 1.54 microcurie/milliliters at the time of its use) to 300 milliliters of the standard Drosophila culture medium. The radioactivity of the original volume was determined with a Geiger counter, and was found to be 265,000 counts per minute/milliliter. The medium was distributed among 50 vials, each containing approximately 6 milliliters. Twenty-five vials were used to test D. melanogaster, and 25 to test D. virilis.

All 25 vials of D. virilis were fertile and produced the average number of pupae. However, only 39 females and 25 males hatched. Without exception, these imagines were morphologically abnormal. The abnormality pertained mostly to the eyes, legs, abdomen, wings, and genitals. Twenty-one females and 17 males survived to be tested for fertility to untreated flies. Of these only 7 females were found fertile.

The low hatch was obviously caused by the lack of ability of the treated imagines to emerge. Dissections of unhatched pupae showed fully formed flies with similar or more extreme abnormalities than those just described.

The number of adult offspring from the seven treated D. virilis females was very low.

The D. melanogaster flies were not tested for mutations. Of the treated flies tested for fertility, 78 out of 130 females and 56 out of 109 males were fertile in pair matings to nonirradiated flies. These produced the normal number of progeny.

Beta radiation proved to be an excellent source of irradiation for Drosophila virilis. The mutations obtained from this treatment are as follows: an eye color, either apricot or an allele of apricot (sex-linked); a wing character, cut or cutlike (sex-linked); scute; extra scutellar bristles; a wing character with unusual venation; another wing character (sterile) in which the wings were folded and rotated 90°; extremely knobby eyes (both males and females also sterile). Several different mutations of the same general type produced flies with extended wings and added effects causing sterility. Among the progeny of yet another tube was a male with one apricot-like eye and the other eye a mosaic of areas respectively normal and apricot-like; when mated, no progeny was obtained.

Perhaps the most unusual and interesting mutation found was of aristapedia-like character. The 10 mutant flies examined (5 males and 5 females) had leg-like aristae, extended wings, crippled legs, and all bristles reduced to the size of hairs. They were nonviable and died soon after emergence.

The mutant is retained by crossing the heterozygotes. Cytological examination of the salivary gland chromosomes of such heterozygotes showed an inversion in the second chromosome. Whether or not this rearrangement is independent of the mutation has not been determined. The spineless aristapedia locus in D. melanogaster is located in the right arm of chromosome 3, which is analogous to chromosome 2 in D. virilis. This coincidence of mutation and rearrangement in the same chromosome suggests that there is a connection between the mutation and the rearrangement.

The present investigation indicates that radioactive P^{32} not only produces mutations in Drosophila virilis, but also chromosomal rearrangements. The tolerance to irradiation with radioactive P^{32} during development is high.

Interpretation-of-data study exercise.—Use the following key (A, B, C) to show that you understand and can interpret Johanna Blumel's study. Decide for yourself what are some of its implications.

A. The statement agrees with the report of the experiment.

B. The statement disagrees with the report of the experiment.

C. The statement neither agrees nor disagrees with the report.

1. During the growth of the experimental flies, the eggs, larva, pupae, and adults would be subjected to beta radiation from both outside and inside their bodies.
2. Mixing radioactive phosphorus in the culture medium used to raise fruit flies tends to cause the flies to become sterile.
3. Radioactive phosphorus seems to affect fruit fly pupae more seriously than it does the larvae or adults.
4. Any genetic effects produced by radioactive phosphorus on adult flies do not show up until the second generation of their offspring.
5. The aristopedia-like mutation must be a dominant trait.
6. The character involving one apricot-like eye and one mosaic eye must be a sex-linked, recessive trait.
7. It would have been much more difficult to inter-

pret the results from this experiment if Blumel had used ordinary fruit flies collected from an overripe melon or other place where these flies gather.

8. The beta radiation from phosphorus 32 seems to affect whole chromosomes just about as often as they affect single genes.
9. It was very probable that similar degrees of exposure to beta radiation would produce as many mutations in other species of animals or plants.

Do X-rays affect the fertility of rabbits?— The following two tables on fetal mortality and fertility in normal female rabbits mated to control males versus irradiated males present data based on experiments by R. L. Murphree, W. M. Whitaker, J. L. Wilding, and J. H. Rust. After the tables is an exercise to give practice in gleaning information from data presented in the form of a table.

TABLE 2.—*Fetal mortality in normal female rabbits mated to control males versus irradiated males*

Treatment of males	Number of matings	Corpora lutea		Fetuses			Percentage of eggs missing	Percentage fetal loss
		Number	Average per female	Number alive	Average number in potential litter [1]	Number dead		
1	2	3	4	5	6	7	8	9
Control	7	74	10. 6	59	8. 4	0	20. 3	0. 0
All irradiated males	26	318	12. 2	146	5. 6	71	31. 8	32. 7
100 r	6	92	15. 3	46	7. 7	18	30. 4	28. 1
200 r	14	163	11. 6	74	5. 3	34	33. 8	31. 5
300 r	6	63	10. 5	26	4. 3	19	28. 6	42. 2

[1] If all live to birth.

TABLE 3.—*Fertility in normal female rabbits mated to control males versus irradiated males*

Treatment of males	Number of matings	Fertile matings		Litters					Young	
		Number	Percent of total matings	Number born	Number resorbed	Average number	Number born alive	Number born alive per mating	Number born	Number born alive
1	2	3	4	5	6	7	8	9	10	11
Control	34	31	91. 2	30	1	7. 7	7. 4	6. 6	233	233
Irradiated	57	47	82. 5	38	9	6. 4	5. 7	3. 8	244	218
100 r	15	12	80. 0	10	2	6. 0	5. 1	3. 4	60	51
200 r	26	23	88. 5	19	4	6. 4	6. 1	4. 5	122	116
300 r	16	12	75. 0	9	3	6. 9	5. 7	3. 2	62	51

Interpretation-of-data study exercises.—Use the following key (A, B, C) to show whether or not the statements below are supported by the data in the two tables.

A. The statement is supported by the data.
B. The statement is contradicted by the data.
C. The statement is neither supported nor contradicted by the data.

____ 1. When normal rabbits are mated, at least 95 percent of all mature eggs are fertilized.
____ 2. The greater the amount of radiation to which the male rabbits were exposed, the greater the chances that the resultant fetuses will die.
____ 3. Male rabbits which received 200 roentgens produced larger litters than were produced by the control males.
____ 4. If some of the males in a population of rabbits were exposed to doses of X-rays as great as 300 roentgens, the total population would decrease in later generations.
____ 5. The reduced fertility of X-radiated rabbits tends to wear off in time.
____ 6. Some females mated to irradiated males produced normal size litters of live young.
____ 7. Individual male rabbits receiving the same amount of X-radiation may be affected quite differently as far as producing live litters is concerned.

___ 8. Female rabbits subjected to X-rays tend to produce dead fetuses.

___ 9. The effect of X-rays on the fertility of male rabbits seems to be more a case of weakening the embryo than failing to fertilize the eggs.

___ 10. Radiation exposures less than 100 roentgens have no effect on the fertility of male rabbits.

Teachers may want to review with their students the fact that ionized materials differ chemically from nonionized materials. For example, if paper moistened with a solution of potassium iodide is touched with the two wires connected to a source of direct current, a brown stain appears at one of the points of contact. Similarly, anhydrous copper sulfate, copper bromide, and copper chloride in crystalline form are respectively white, brown, and green. When water is added, blue colors appear which suggest the formation of cupric ions.

One can show that the air in the immediate vicinity of a source of radioactivity is ionized. Arnold Rubin and T. H. Diehl have shown that a radium button will allow a spark to pass in a circuit connected to a spark coil which is being energized by a 3-volt battery. It would be interesting to compare the degree to which paper disks soaked in uniform activity solutions of a variety of isotopes would produce this effect. The discharging of electroscopes by nuclear radiation has been applied in the design of small meters to be worn in the pockets of people who work in radiation fields. The total amount of radiation to which the worker has been exposed is recorded. These pocket dosimeters are similar to the Lauritsen electroscope (fig. 20).

Before a pocket dosimeter is used, the quartz fiber is bent away from its normal position by being subjected to a voltage of approximately 160. This electrical charge is effectively trapped and cannot be neutralized until ionizing radiation dislodges electrons from the walls of the ion chamber. As the fiber moves closer to the frame, a hairline image of the fiber moves across a scale recording the total amount of radiation to which the ion chamber has been exposed. Teachers may demonstrate the fundamental characteristics of the dosimeter by using an ordinary electroscope and paper disks which have been soaked in one microcurie per milliliter solutions of gamma-emitting isotopes.

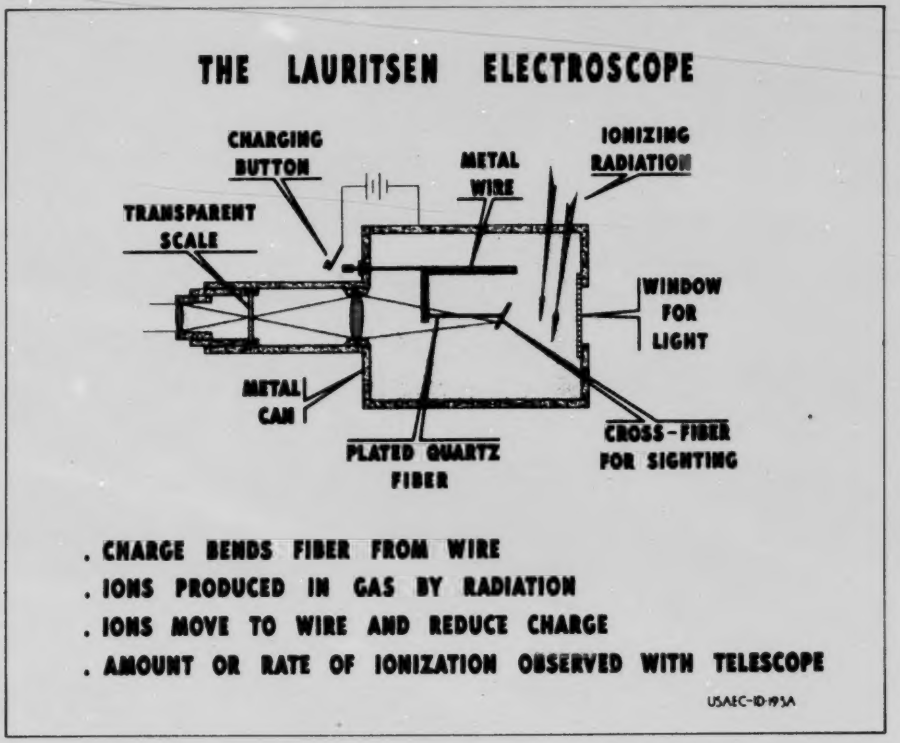

FIGURE 20.—Pocket dosimeters are special adaptations of the Lauritsen electroscope.

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How ions may serve as condensation nuclei is clearly known to everyone who has seen vapor trails left by high flying aircraft. This phenomenon is also applied in the design of the Wilson cloud chamber. Descriptions of homemade cloud chambers are already in the literature. A photograph of one type appears here (fig. 21).

Cloud chambers have played such an active role in helping physicists identify and describe the characteristics of nuclear particles that teachers may want to give their students some exercise in the interpretation of cloud chamber tracks. Perhaps the diagrams in figure 22 could be reproduced on the chalkboard and questions, such as those indicated in figure 22, could be used to lead the class discussion.

As demonstration that a stream of electrons is equivalent to a beam of beta particles, a student of Fred Moore, a science teacher in Michigan's Owosso High School, removed the horizontal and deflecting plates from a small TV tube so that when it was turned on it gave a brief spot of light in the middle of the screen. The tube and its original power supply were mounted on a breadboard. After the spot of light became visible to the class, a magnet, moved around the forward portion of the neck of the tube, caused the spot of light to move.

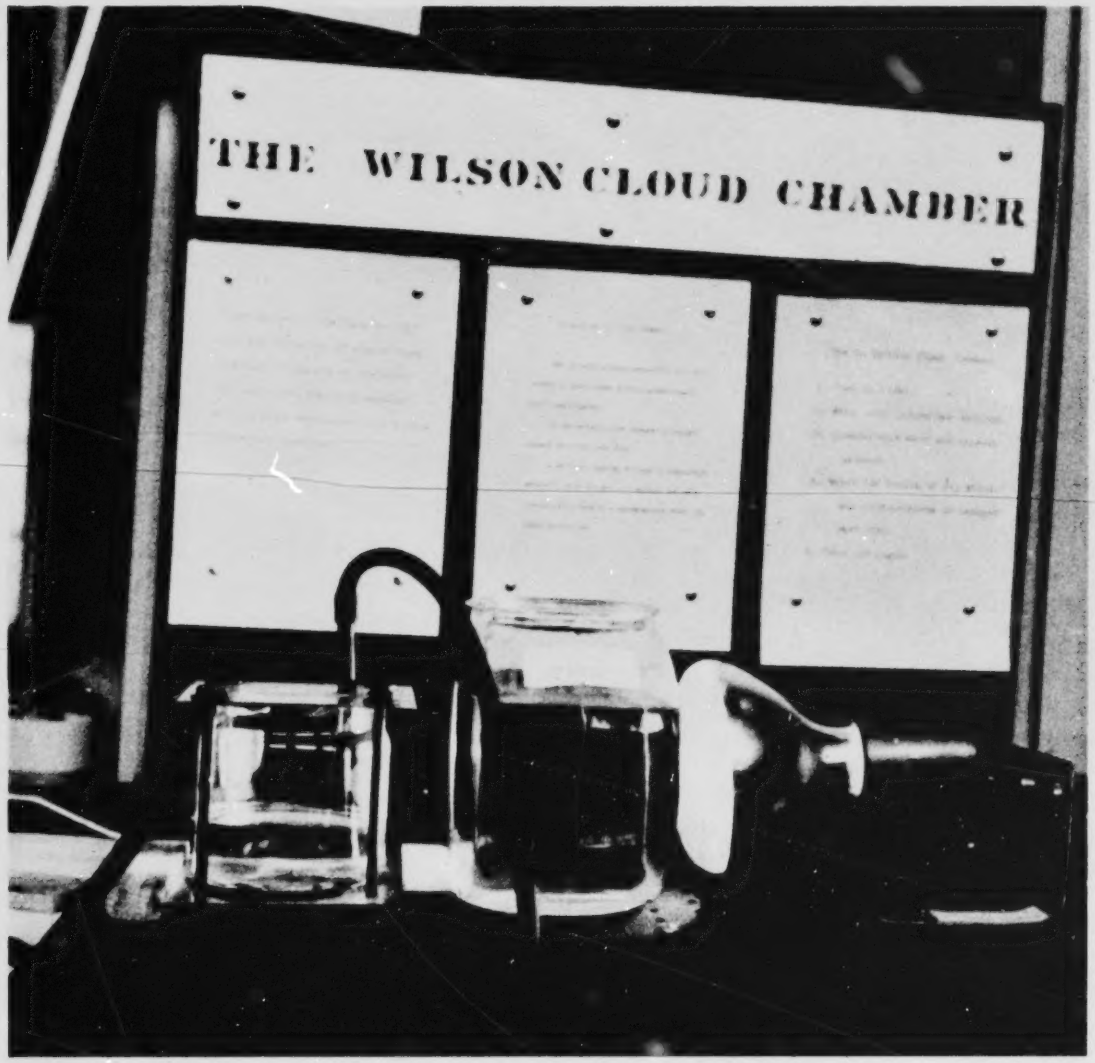


FIGURE 21.—Student-made cloud chamber.

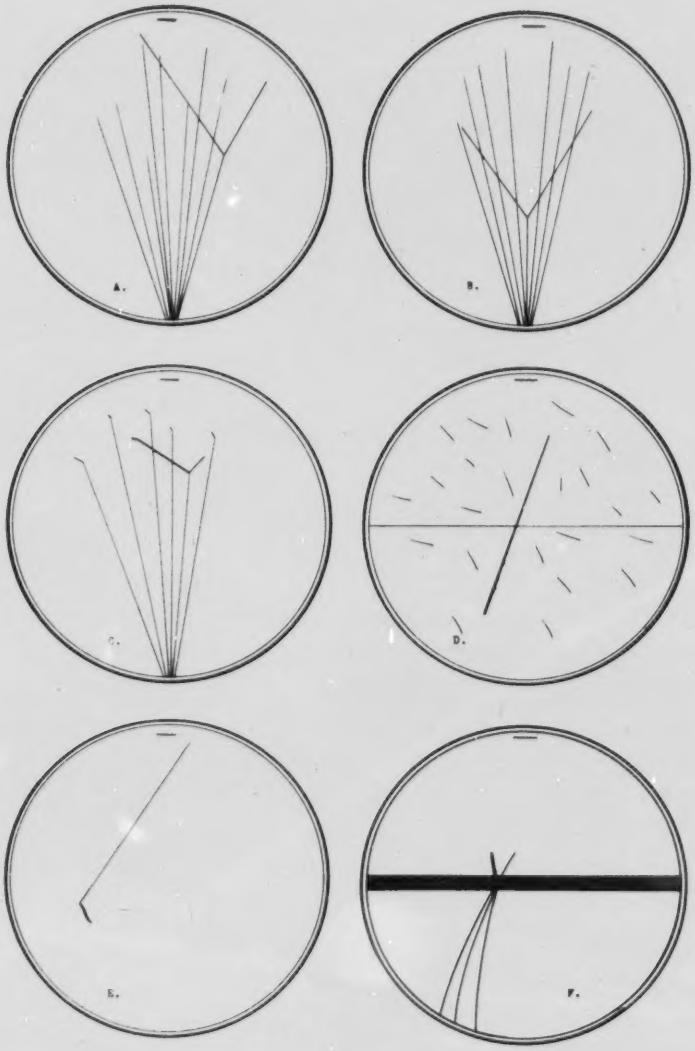


FIGURE 22.—Reading Cloud Chamber Tracks. *A.* Alpha particles are shown streaming through a cloud chamber. What kind of a particle must have been hit and knocked out of the way toward the left? Would it be lighter or heavier than the alpha particle that hit it? Would it have the same or opposite charge as the alpha particle? *B.* One of the alpha particles streaming across this cloud chamber has struck a helium nucleus. How must the mass of the alpha particle compare with the mass of a helium nucleus? Do the two particles carry the same charge? Was the helium nucleus charged before it was struck by the alpha particle? *C.* In this case, an alpha particle has collided with an atom of some element. After the collision the alpha particle glanced off toward the top left and the atom it hit recoiled to the right. Was the atom heavier or lighter than the alpha particle? Did the atom become a positive or a negative ion? Could it have been an oxygen atom that the alpha particle hit? *D.* An atom of uranium was apparently at rest in the thin foil that stretches across the cloud chamber, then it was "triggered off" by a passing neutron. Were the two fission products of equal mass? What two elements might have been formed by the fission of the uranium atom? Are the fission products ionized? Were any new neutrons produced? *E.* Some kind of a collision has produced a light particle that streams toward the negatively charged plate and a much heavier particle that recoiled in an almost opposite direction. If it was a nitrogen atom that was hit, what kind of particle must have hit it? Was the projectile charged? Was it heavier than the two particles which left the tracks? *F.* The particle which produced the heavy track in this photograph had passed through a thick block of lead and was near the end of its path. It showed a slight curve toward the negative plate but other photographs showed a similar curvature toward the positive plate. How must this projectile differ from alpha, beta, or gamma rays?

If the students already know the relationship between magnetism and electricity, it is easy for them to see that beta particles might have magnetic properties which are influenced by the electrical field. Quoting Moore:

> This helps the students to see that the invisible particles we talk so much about are really there and that they are electrical.

Phosphorescence and Fluorescence

The phenomena of phosphorescence and fluorescence may be brought to the student's attention by luminous instrument dials. The paint used to print these dials may contain a phosphorescent or fluorescent compound. Either will glow in the dark. Fluorescent materials, however, will glow only when atomic particles or rays are striking them. Phosphorescent materials can store up such rays, so to speak, and then give them back slowly in the form of a soft glow. On fluorescent luminous dials, the paint contains a mixture of radium and fluorescent compounds. Particles from the radium continually bombard the fluorescent material and cause it to glow. Phosphorescent dials contain no radium.

Directions for making spinthariscopes have already been widely distributed and several toy models are readily available. Similar observations can be made simply by looking at a radium watch dial with a magnifying glass in a totally dark room. Perhaps students can appreciate the starlike flashes more readily if they look upon whizzing atomic particles as carrying energy just as a baseball does when it leaves a bat. They know that the baseball can do things to their hands when they try to stop it. Its energy of motion can be changed into heat or other forms of energy. The whizzing atomic particles can do things to the atoms of the fluorescent material on the screen. Perhaps they rub their energy off onto some of the electrons that surround the nuclei of these atoms and thereby boost them into higher energy levels. As soon as the whizzing particle passes by or settles down, the high energy orbital electrons return to the level they ordinarily occupy and give up the newly acquired energy as a flash of light.

Phosphorescent materials are similar in some ways and different in others. Their electrons can also be boosted up into high energy levels, but some of them stay there for a time after the atomic particle or ray has acted upon them. For this reason, phosphorescent materials glow more slowly for a longer time after being subjected to bombardment than fluorescent materials.

Chapter IV

Classroom Demonstrations and Laboratory Exercises Involving Nuclear Radiation

There are several reasons why teachers may want to increase the emphasis on nuclear science in their classrooms. Many of the concepts in high school biology, chemistry, and physics are very closely related to atomic structure, nuclear energy, and nuclear radiation.

To the extent that students bring into the classroom questions prompted by their everyday reading, radio listening, and television watching, teachers can expect an increasing number of questions dealing with nuclear energy.

More than 35,000 laboratories in the United States are licensed to work with radioactive materials. In effect, each of these laboratories becomes a potential employer for young people trained and oriented in handling radioactive materials.

So long as a possibility exists that our Nation can be involved in atomic warfare and fallout hazards, there is a great need for everyone to understand the fundamentals of atomic energy. The Nation needs a corps of people trained to predict the areas of radiological contamination resulting from fallout, determine the actual areas and concentration of radioactive contamination, and to carry on rescue operations in fields of high radiation, protecting themselves and others from undue exposure, and helping all people to keep their radiation exposure to a minimum. In the public schools, teachers can make a great contribution by presenting the fundamentals of nuclear science in an interesting, realistic, and accurate manner.

At the time this publication is being prepared, we are on the threshold of developing power for peacetime purposes from nuclear reactions. To insure that this important resource makes its greatest possible contribution to mankind will call for wise decisions on the part of many people as well as for a group of highly trained and dedicated nuclear scientists.

For reasons such as these, teachers, especially science teachers, are being encouraged to extend and enrich the treatment of nuclear science in their high school general science, biology, physics, and chemistry classes. Furthermore, the low cost of small quantities of radioactive materials, the availability of instruments, and the simplicity of procedures to exploit the potentialities of tracer isotopes combine to produce an interesting challenge to science teachers.

Following are basic rules for handling radioactive materials:

1. Use only those quantities of radioactive materials for which no licensing or special regulations are required.
2. Be sure you know what nuclear reaction is producing the radiation with which you are working.
3. Know exactly what quantity of unstable nuclei for which you are responsible.
4. Acquaint yourself with the characteristics of the radiation emitted by whatever unstable nuclei with which you will be working.
5. Before obtaining the necessary radioactive materials, be sure all of your exercises are sufficiently well planned to allow you to use the short-lived materials before they undergo extensive decay.
6. From the moment your radioactive materials arrive, be sure your storage facilities are such that you will know precisely where each bit of it is until you are through working with it and it has been flushed down the drain or otherwise disposed of.

Plant Absorption

Teachers can well begin their work with radioactive materials by investigating the absorption of these materials by plants. The illustrative exercise presented here attempted to shed light on the question of whether growing plants would absorb fission product fallout from the soil.

To represent the fission product fallout, 6 isotopes were selected which are available in 10 microcurie quantities. Two milliliters of 1 microcurie per milliliter solutions of each of the isotopes were placed in containers. Eight milliliters of water were added to each.

After the solutions of radioactive materials had been prepared, the following weeds, growing vigorously at the time, were selected: one with a blossom (dandelion), one with seed pods (wild mustard), one with a bulb (wild onion), and one (clover) which absorbs strontium 90 and eventually deposits it in dairy products. The plants were washed clean with minimum injury to the roots and dead materials were stripped away. Then the plants were placed in the radioactive solutions.

At the end of 64 hours, parts of a leaf or of whole leaves were selected from each of the plants in each of the 6 preparations. These were spread out on 35-millimeter cards and wrapped with transparent plastic. (*Note: Rubber gloves should be worn at all times when you handle any material suspected of containing radioactive isotopes.*) These small sample cards were to be used to test for the presence of absorbed radioactive materials without having to remove the whole plants from the solutions. The use of 35-millimeter size test cards, after the materials were exposed to X-ray films (if autoradiographs were obtained) made it possible later to frame the films with 2″ x 2″ binders and use them in a classroom projector.

At the end of 120 hours, the complete plant preparations were removed from the solutions, washed in running water to free them of adhering radioactive materials, laid out on 5″ x 7″ cards, wrapped with transparent plastic, and put in lightproof wrappings with 5″ x 7″ sheets of X-ray film. The accompanying photographs (figs. 23, 24, and 25) show the results from five of the isotope solutions. No absorption of chromium 51 is observable and there is reason to question the calibration of the original quantity of this material.

Although autoradiography provides an interesting way to study the absorption of radioactive materials by plants, it does not lend itself to accurate quantitative studies. Consider, for example, photograph A in figure 25. One might attempt to interpret quantitatively the deposit of radioactive material in the various plant tissues or organs. The greater exposure of the overturned tip of the dandelion leaf shows clearly how significant the distance is between the plant tissue and the photographic film. To make quantitative investigations, procedures would have to be developed to insure that each tissue or organ was the same distance from the film.

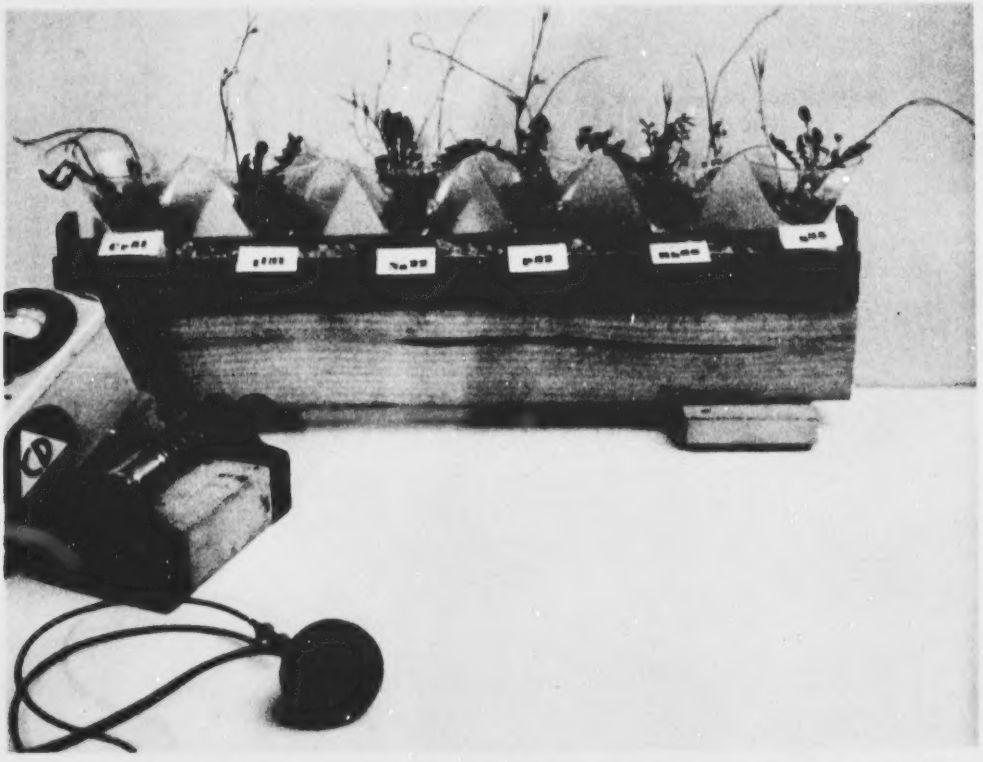


FIGURE 23.—This arrangement of the plant materials should be securely fastened to a shelf to avoid spills.

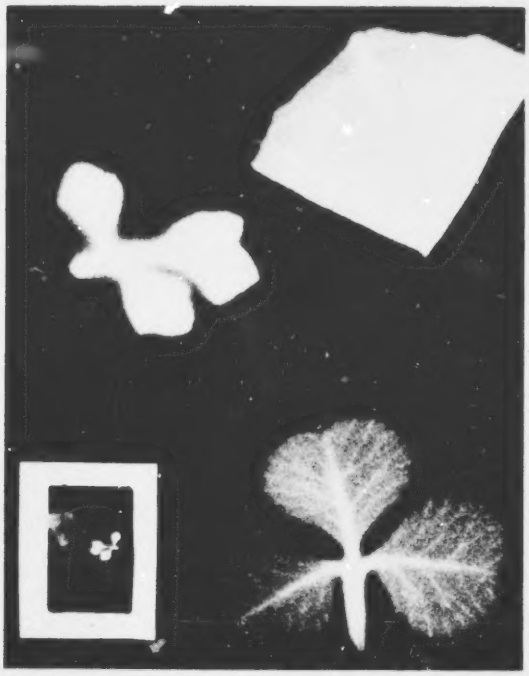


FIGURE 24.—Enlarged test film from sodium 22 preparation. The film was exposed to the test card for 11 hours, developed 5 minutes, and fixed for 10 minutes.

The basic procedure outlined in this exercise lends itself to additional investigations. One might use duplicate or triplicate plant preparations and restore one set of the plants to pure water to see whether the absorbed radioactive materials are thrown off by the usual physiological processes. Selecting plants with variegated leaf patterns might lead to interesting results. Additional ideas are presented in chapter V of this publication.

Animal Absorption

Although many teachers tend to avoid experimentation with the higher animals, effective techniques have been developed which allow teachers and their students to explore the absorption of radioactive materials by the simpler animals.

Several teachers have reported attempts to observe the absorption of phosphorus 32 by fish. The usual procedure is to dilute 10 microcuries of phosphorus 32 with something less than a liter of water. Small fish, usually goldfish, are left in the solution from 1 to 10 days. When the fish are removed from the solution, the soft tissues are removed (using rubber gloves) and the skeleton is prepared for autoradiography. Suggested exposure times for the prepared skeleton on no-screen X-ray film range from 24 through 120 hours. Teachers who have encountered discouraging results with this procedure have obtained better results in some cases, however, when the phosphorus 32 was taken up by food plants or injected into earthworms or other small animals and fed to the fish. The thickness of the skeleton materials, coupled with the high energy of the beta particles from phosphorus 32, precludes getting a sharply defined autoradiograph from this procedure.

Bill Whitehurst of Peoria, Ill., reports the following procedure for studying the absorption of phosphorus 32 in the frog:

Inject one microcurie of the phosphorus 32 into the bodies of three earthworms. Small injections along the bodies will bring best results. Force feed the worms to the frog carefully (rubber gloves). Place the frog in 300 milliliters of water in a container of such size that the bottom will be covered to about a depth of one-half inch.

The rate at which the radioactive material is excreted by the frog may be estimated by taking one milliliter samples of the water from the container at convenient intervals, evaporating this water on small aluminum foil disks (planchets), and then placing the aluminum disks near a Geiger counter tube.

After approximately 24 hours, the animal should be killed and 0.025 gram samples of blood and other body fluids collected. Similar weight samples of all the other organs should be prepared.

The body fluids can be transferred immediately to aluminum foil planchets, dried, and counted with the Geiger counter. A few drops of alcohol should be added to the tissue or organ samples which are then ground to a paste with a mortar and pestle, washed onto planchets, dried, and counted as promptly as possible.

The remaining parts of the frog can be sliced with a razor blade to make autoradiographs as in the previous plant absorption exercises. If the bones are sandpapered down to thin strips before placing them on the X-ray film, the autoradiograph will be a more accurate silhouette.

The data obtained from this exercise should be studied to determine when the excretion rate began to rise abruptly, which organs contain the greatest concentration of phosphorus 32, and so on.

In another investigation, the author attempted to determine whether or not aquatic animals differ in their absorption of fission fallout materials from their water environment:

A wish to use autoradiography and to project the autoradiographs for classroom study purposes led to collection of specimens of minnows, crayfish, and

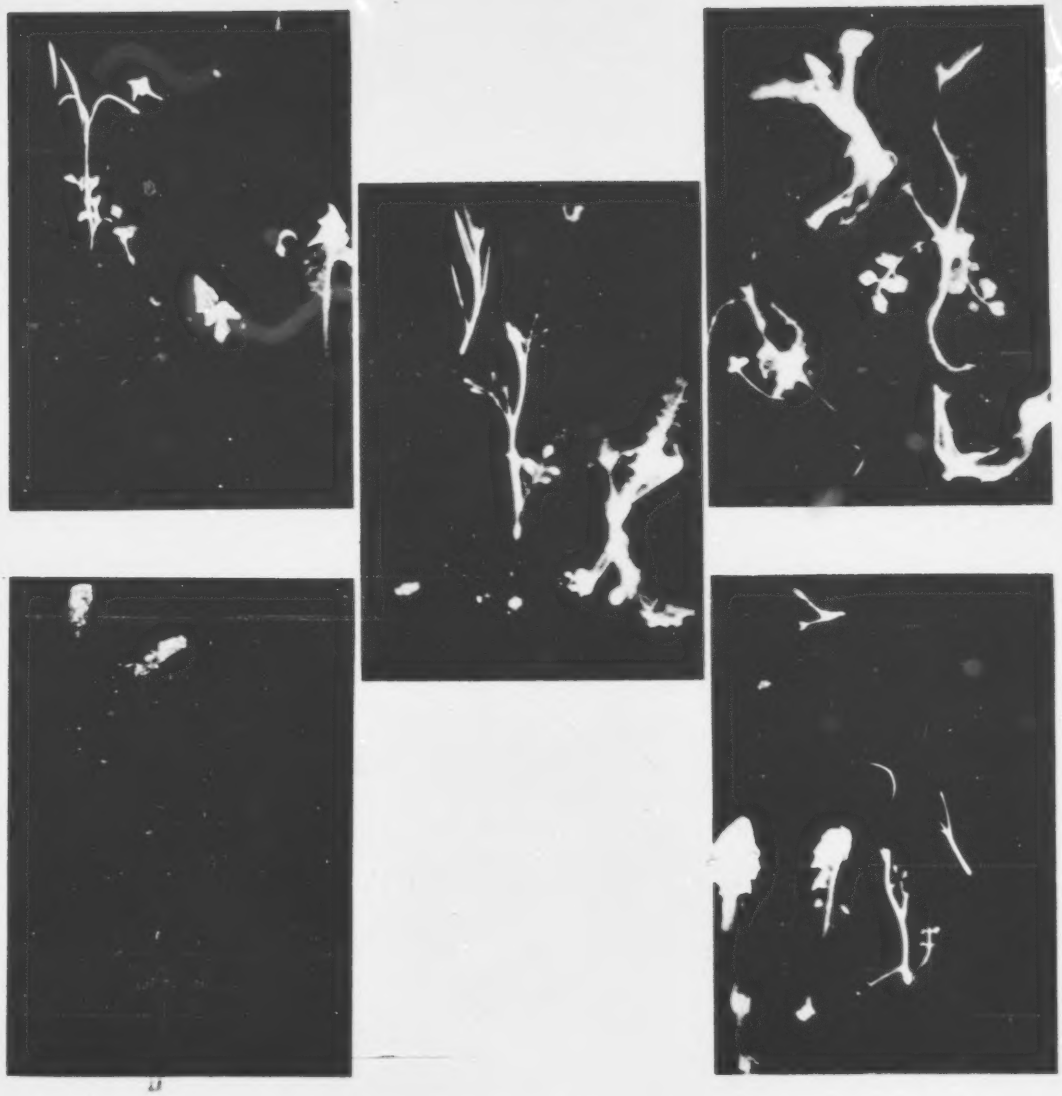


FIGURE 25.—Contact prints from X-ray film exposed, for varying numbers of hours, to plants left for 120 hours in different preparations. A.—10-hour exposure to plants left in 10 milliliters of water containing 2 milliliters of 1 microcurie per milliliter iodine-131, 20 days old. B.—6-hour exposure, rubidium 86. C.—6-hour exposure, phosphorus 32. D.—15-hour exposure, sulfur 35. E.—10-hour exposure, sodium 22.

salamanders approximately 35 millimeters in length from a small stream. Specimens of each of the three species were placed in approximately 20 milliliters of water containing 2 milliliters of 1 microcurie per milliliter solutions of isotopes such as iodine 131, sodium 22, phosphorus 32, and sulfur 35.

For periods of ranging up to 80 hours, none of the minnows absorbed observable amounts of any of the isotopes from the solution. The crayfish and salamanders, on the other hand, showed absorption ranging up to 1,000 counts per minute on the civil defense-type Geiger counter with the probe held approximately one-half inch from the specimens.

The test animals were removed from the isotope solutions, washed clean under running hot water, embedded in paraffin blocks, frozen, and sectioned with a razor blade. Although the results from this procedure were, in general, discouraging, the shortcomings appeared to be more in connection with the efficiency of the technique than in the theory underlying its design.

At some sacrifice of detail, autoradiographs of the crayfish were prepared by simply pressing the specimen

as flat as possible on cardboard, wrapping the preparation with transparent plastic, and placing the preparation in contact with no-screen X-ray film. An accompanying photograph (fig. 26) illustrates one such result.

FIGURE 26.—A small crayfish left for 118 hours in 20 milliliters of water containing 2 milliliters of 1 microcurie per milliliter sodium 22 was removed, washed clean, pressed flat, and left in contact with no-screen X-ray film for 10½ hours.

The improvement of simple animal absorption exercises remains a challenge to teachers. Many of the phenomena of animal life might be clarified effectively by use of tracer isotopes. It would be interesting, for example, to study not only the absorption of various elements by animals but also the transportation of the elements within the organs of the animals and their eventual excretion. Tracing the deposition of materials during spectacular bodily changes holds special interest. Insect metamorphosis, egg formation, pregnancy, and regeneration or other tissue-repair processes might lend themselves to isotope investigation.

Uranium, Thorium, or Radium Compounds

In 1896 Becquerel observed that crystals of uranium salt emit radiation capable of penetrating opaque materials, affecting photographic film, and discharging electroscopes. Many exercises have been developed since then to shed additional light on this phenomenon.

In connection with her project to be reported to the Kansas Junior Academy of Science, Sandra Hodgson of the Manhattan, Kans., High School, developed the following procedures:

Uranium nitrate was chosen as the starting material for the preparation of the active sources. To obtain a higher degree of purity, reagent grade material was recrystallized. The crystalline form was dissolved in reagent grade nitric acid, and the volume of solution was reduced to near dryness with a heat lamp. Six hundred milliliters of distilled water were added and the solution heated. Fifty milliliters of ammonium hydroxide were added slowly over a period of 20 to 30 minutes with continued stirring. The hot solution was filtered through a double layer of ashless filter paper and the precipitate was allowed to dry overnight. The filter papers containing the precipitate were transferred to a platinum crucible, dried under a heat lamp, and ignited to the black oxide, U_3O_8, by means of a Meeker burner.

Miss Hodgson hoped to prepare uniform distributions of the precipitated uranium oxide on filter paper disks. She ran into considerable trouble in doing this. Brushing the material onto the filter paper and bonding with a spray of acrylic resin produced neither a uniform layer nor complete bonding. Improved results were obtained, however, by mixing equal volumes of molten paraffin and acetone, adding the powdered oxide, and applying the mixture to filter paper. Repeated heatings of the filter paper tended to obtain a uniform distribution. Using these filter paper sources, Miss Hodgson was able to obtain sharply defined silhouettes by sandwiching opaque materials between the filter paper preparation and no-screen X-ray film. Her exposure times ranged between 3 and 24 hours.

"The clock that took its own picture" has become a satisfying exercise for many teachers. The detail of the autoradiograph can be improved if the dial is removed from the clock or watch and separated from the X-ray film by nothing thicker than transparent plastic. Exposure times are difficult to estimate because of the wide variation in activity of luminous paints used on dials. Results seem to range from a few hundred counts per minute to more than 5,000 per minute when checked with the civil defense-type Geiger counter with the probe at a distance of approximately one-quarter inch from the dial.

By mounting the dial on a card and placing the preparation over the film opening of a small box camera, loading the camera with ordinary film, and starting exposures with 2 hours and doubling the exposure time for each frame to be rolled in contact with the dial, a wide range of exposure times can be readily investigated. Again, by using a dial less than 35 millimeters

in diameter, the resultant films can be framed and used for projection purposes.

Autoradiographs can be used very effectively to show the distribution of radioactive materials in ore specimens. If the distribution of the radioactive material follows a crystalline pattern and the ore sample is ground flat on one surface, results are improved. An accompanying photograph illustrates the results (fig. 27).

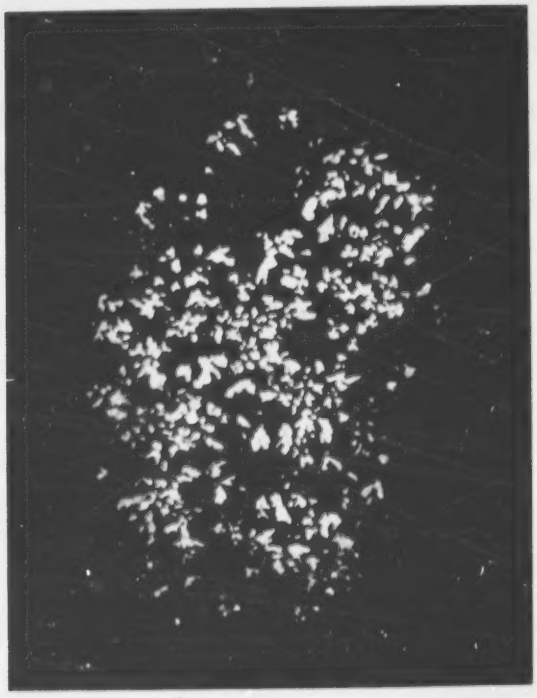


FIGURE 27.—A contact print from a 5″ x 7″ sheet of no-screen X-ray film in contact with a polished ore specimen (uraninite, gummite, uranophane, and crysolite). Exposure 4 hours.

Although Kenneth Vinten of the Canal Zone knew that a Geiger counter gives a good indication of whether or not an ore sample contains uranium, he needed a method to identify uranium when he didn't have a Geiger counter. He suggests the following procedure:

Step 1. Grind the ore sample thoroughly.

Step 2. Gently boil for 15 minutes a 5-to-10 gram sample in enough 1-to-1 sulfuric acid to prevent spattering.

Step 3. Place the residue and the acid solution under an ultra-violet light. A yellow or greenish-yellow fluorescence in either strongly suggests that the ore sample contains uranium.

In this analytical test it is assumed that the uranium in the ore sample is converted into sulfate salts and that only these salts will give the yellow or greenish-yellow fluorescence.

Don Harrod, chemistry instructor in Michigan's Benton Harbor High School, reports a high level of interest among his chemistry students in a laboratory exercise involving the separation of uranium from its daughter products. His procedure involves the following steps:

1. Prepare a saturated solution of ammonium nitrate in distilled water.
2. To 20 milliliters of this solution, add 5 grams of uranyl nitrate.
3. Transfer 5 milliliters to a small petri dish and the other 15 milliliters to a separatory funnel.
4. Add 75 milliliters of ethyl acetate to the separatory funnel and shake it for one minute.
5. Draw off the lower aqueous thorium and protactinium layer and transfer 5 milliliters each of the aqueous and ethyl acetate solutions to two petri dishes.
6. Measure the beta activity by holding the Geiger counter tube equal distances from each of the three samples.

In this exercise the two alpha-emitting uranium isotopes are separated from their beta-emitting daughters. The uranyl nitrate is extracted into ethyl acetate while the thorium and the protactinium nitrates remain in the water.

Fission Product and Other Environmental Radiation

Applications of nuclear energy in the design of military weapons has brought with it the problem of fission products being projected into the upper atmosphere and later falling and accumulating in the soil. Teachers should feel called upon to shed some light on this problem of radioactive fallout because it may have far-reaching biological implications.

Clarification of the basic reaction in the fission of uranium-235 atoms and the subsequent production of their fission products can best be obtained by visualizing the reaction. Techniques for doing this have been covered in chapter I. The accompanying photograph represents an additional idea (fig. 28).

William Crumrine, instructor in the Marshall, Mich., High School, has modified a typical chemistry demonstration to suggest how fission

T. L. Handy High School, Bay City, Mich.

FIGURE 28.—Uranium 235 fission model. Before release of neutron to which student points, a uranium 235 nucleus occupied the same position.

fallout takes place. Following is his description of the demonstration:

In this demonstration we use a common simple combination chemical reaction (zinc and sulfur to yield zinc sulfide) to simulate an atomic explosion and the resulting white powdered zinc sulfide to simulate radioactive fallout. By using a map or chart (a regular aeronautical chart is ideal) directions and distances to large cities can be determined.

Letter the names of the cities to be used on small pieces of white cardboard, fold in half so that they will stand, then place these name cards on the sheets of black paper. On a very large table or the floor, place these cards at the determined positions. A small electric fan can be used to simulate the prevailing wind for the particular geographical area.

Place a ringstand on the city to be bombed, attach a ring, add a wire gauze, and a pile of well-mixed material containing 5 grams of zinc dust and 2 grams of powdered sulfur. If more fallout material is desired add 2 grams of finely powdered calcium hydroxide. Adjust the ringstand to the proper height and place a lighted Bunsen burner under the mixture. (CAUTION: *Everyone should stand back at least 10 feet as the reaction takes 20 to 30 seconds to take place and is rather violent.*)

Teachers or their students in several parts of the country have built collectors which allow them to observe and measure the quantity of fission products falling from the atmosphere. Quoting from an exercise suggested by James M. Wallace of Jackson, Mich.:

To build a collector all you need is an 8" x 10" sheet of metal, cloth, petroleum jelly, cellophane or its equivalent, no-screen X-ray film, and developing chemicals. Wrap the sheet of metal with a cloth and cover it with petroleum jelly. Place it on top of your school or other appropriate location and leave it for 1 or 2 weeks. Bring it down, wrap it with cellophane, and take it to a darkroom. In the darkroom, place the film, emulsion side down, over the plate and cover with a book to hold the film close to the plate. After 24 to 40 hours, remove the film and develop.

The satisfaction obtained from this procedure may be heightened by putting a lead silhouette on a portion of the collecting plate. By shielding the film from the effects of any radioactive material on the plate, you will have additional evidence that the film was exposed by the fallout material.

Plotting Radiation Fields

Teachers may want to take part in training actual monitors for measuring radiation fields in time of nuclear warfare. The intensities of the radioactive sources required to simulate a radiation field suggest that this exercise would not be suitable for high school age students. It would be interesting, however, to see whether

FIGURE 29.—Michigan teachers participate in a problem that involves plotting a simulated fallout radiation field.

FIGURE 29.—Continued.

FIGURE 29.—Continued.

a simulated fallout radiation field could be prepared using a 10-foot-square sheet of cardboard to which had been attached small paper disks soaked in 1 microcurie per milliliter solutions of cobalt 60, sodium 22, or some other gamma-ray emitting isotope. The procedure would be similar to that suggested in the following laboratory exercise guide sheet:

Guide Sheet for Laboratory Exercise

What you can learn from this exercise:

How to read a Geiger counter accurately.

How to translate a survey instrument's readings into a picture of radiation sources and intensities in an area.

We presume you already know:

The difference between the 1X, 10X, and 100X ranges on the counter.

That the general geometry and/or peculiar shielding effects while the counter is being read may affect its readings.

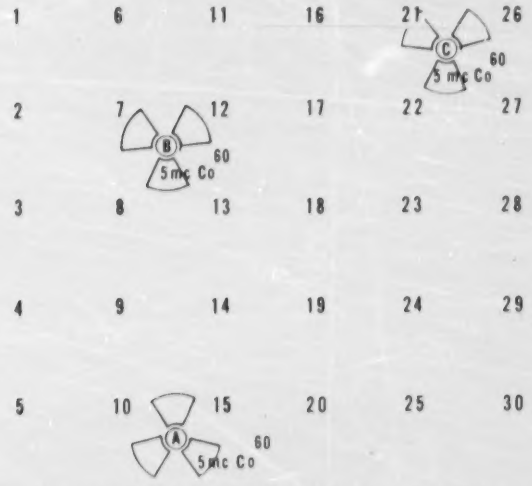
How isobars are drawn to show areas of equal atmospheric pressure on weather maps.

How contour lines show elevations on topographic maps.

That the intensity of radiation received at any point from a source depends directly upon the intensity of the source, *but,*

If one of two equal point sources is twice as far away, the radiation received from the more distant one is only a fourth as great.

A Practice Radiation Area



In the practice radiation field above, the numbers show the stations at which readings are to be taken and the letters show radiation sources.

Here's the general idea:

It's a well-known fact that a uranium prospector can't take readings over each square foot of the country in which he hopes to find pay dirt. His problem is to get a clear picture of where ore bodies are without covering the whole country. Similarly, if nuclear war should be waged, then after a bomb burst or after the population has been exposed to radioactive fallout, only scattered estimates could be obtained of radiation hazards. Ways must be devised to estimate intensities throughout the whole affected area.

By taking scattered readings over the area and then connecting all areas showing equal radiation intensities, two things are accomplished. First, it becomes possible to estimate how strong the radiation is where no reading could be taken and, second, it becomes easier to spot the places from where the radiation seems to be coming.

In this exercise a part of the school ground has been converted into a practice radiation field. Cobalt 60 sources have been "planted" to provide the radiation. Thirty spots have been marked where readings are to be taken. Your "map" of the area will then show the isointensity lines based on your readings.

Be alert to the following:

Remember that your body will get the same radiation as that being picked up by your Geiger counter. These radiation intensities are, of course, harmless. Use this opportunity to learn how to get around in a radiation field and still keep your "dose" as low as possible.

Take readings under .45 mr/hr on the 1X scale and readings between 0.45 and 4.5 on the 10X scale.

Take some practice readings at your first station to see whether there are things you can do or avoid doing to be sure that you get the same result another person would get at the same spot.

To reduce shielding effects or other sources of error, take readings while you are facing north, east, south, and west. After correcting each reading for special instrument error, use the average reading at each station.

This is what to expect:

Here is an example from a similar exercise. At station 9, let's say, the Geiger counter would pick up radiation from the three sources planted at A, B, and C. We can assume that the Co^{60} sources are fresh. The intensity of the radiation received at station 9 from each of the sources follows the formula:

$$\text{mr/hr} = \frac{1.59 \times \text{mc of } Co^{60}}{D^2}$$

mr/hr = milliroentgens per hour
mc = number of millicuries of Co^{60}
D = distance in yards from source
1.59 = number of milliroentgens per hour received from 1 millicurie of Co^{60} at a distance of one yard

Thus at station 9, the radiation rate becomes:

$$\text{mr/hr} = \frac{1.59 \times 20\text{mc of } Co^{60}}{3\text{yd} \times 3\text{yd}}$$

$$\text{mr/hr} = \frac{1.59 \times 20}{9}$$

Intensity at station 9 from "A" = 3.53mr/hr

Similarly, from source B — $\text{mr/hr} = \frac{1.59 \times 5\text{mc of } Co^{60}}{3\text{yd} \times 3\text{yd}}$

$= .88\text{mr/hr}$

Since source C is the same as B, we can use what we know about A to estimate how much source C will produce at station 9. Since station 9 is three times farther away, we know that the radiation received will be one-ninth as great. For this we use the inverse square law:

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$

$$\frac{8.8\text{mr/hr}}{I_2} = \frac{9\text{yd} \times 9\text{yd}}{3\text{yd} \times 3\text{yd}}$$

$$I_2 = 0.1\text{mr/hr}$$

From all this we can now expect the Geiger counter to read at station 9 the total of these three separate rates:

Total radiation received at station 9 = 3.53mr/hr
+ 0.88mr/hr
+ 0.1mr/hr
= 4.51mr/hr

A second example will not only add to your understanding but, we hope, also teach a safety lesson. Suppose a student becomes tired between Stations 21 and 22 and sits down. To get out of the way of the other students he chooses a spot that puts him only 0.6 inch from source C. How hot a spot is he on? Again we know that:

$$\text{mr/hr} = \frac{1.59 \times 5\text{mc of } Co^{60}}{6/36 \times 6/36}$$

$= 28{,}620$

At this rate he will have to sit there only a few minutes to pick up about as much radiation as is ordinarily used in a chest X-ray.

Procedure:

1. Record your readings at each of the 30 stations on the data sheet below. It makes no difference where you begin. Remember to apply your calibration curve before averaging your 4 readings at each station.
2. Now enter the corrected average reading at each station on the practice chart or "map" below.
3. Sketch a line enclosing all stations that show readings above 20mr/hr and similarly for stations between 15 and 20mr/hr; 10 and 15mr/hr; 5 and 10mr/hr; 2.5 and 5mr/hr; and 0.1 and 2.5 mr/hr.

Questions:

1. Assuming that the sources of radiation in this practice exercise were actually "hot spots" following a radioactive fallout, at which stations would civil defense rescue workers be exposed to dose rates greater than 10mr/hr?
2. Would the accumulation of radiation from several ore bodies in the same general area be likely to throw a prospector off the track by giving higher readings than those that would be received directly over one of the bodies? Why?

Data Sheet

Station	Readings					
Range	North	East	South	West	Corrected	Average
1						
2						

etc.

Practice Chart

1	6	11	16	21	26
2	7	12	17	22	27
3	8	13	18	23	etc.

Fallout Products

Interesting science projects can be planned to investigate whether or not plants and animals store up fission fallout materials. Atomic bomb tests have scattered enormous numbers of different kinds of radioactive atoms throughout the world. At least two of these fission products have such long half-lives that they will continue to move into and through food chains and nutrition cycles for many years.

Each kind of plant or animal tends to select for storage certain elements. Organisms differ

in the degree of concentration of any one element. For example, if smart weed and wild rye are grown together, the smart weed may pick up from the soil twice as much of some kinds of radioactive wastes as of other kinds. Algae and spirogyra may absorb 6 to 8 times as much of some elements as do euglena and volvox. Black crappies will concentrate nearly twice as much strontium phosphate in their skeletons as blue gills. Science projects to explore this problem would require students to collect and extract the mineral content from large quantities of plant or animal material. Unless the mineral content can be concentrated into relatively small volume, the counts, because of the absorption of fallout, would scarcely reach levels adequate to register on the usual type of Geiger counter.

Miscellaneous Demonstrations and Exercises

Just as tracer isotopes have been effective in helping solve research and industrial problems, so do they hold promise of helping teachers improve their laboratory demonstrations and exercises. Ingenious teachers everywhere are finding that Geiger counters and photographic films add a new method whereby abstract and complex phenomena can be more effectively presented or explored.

Representative of exercises developed by a group of science teachers in Connecticut is one to show the speed of diffusion of sodium ions in water. Eight milliliters of water were placed in a small graduated cylinder. With the greatest possible care, a milliliter of 1 microcurie per milliliter solution of sodium 22 was added to the bottom of the cylinder. Readings were begun immediately with the Geiger counter held against the side of the cylinder at the lower and upper levels of the liquid.

The addition of radioactive isotopes to electrolytic solutions makes it possible to observe the mechanisms of the plating process more easily and thereby to understand them better. Using radioactive isotopes clarifies the action of ionic exchangers.

Several exercises, described in other literature, employ bacteria which are cultured in nutrient media containing phosphorus 32, sodium 22, or carbon 14. Colonies of the bacteria may yield very satisfying autoradiographs.

Teachers can rather easily simulate applications of radioactive materials to industrial problems. Fluid-flow indicators, level indicators, and compactness gages are good examples. Less than 0.25 milliliter of one microcurie per milliliter solution of cobalt 60 in a sealed capsule is adequate to provide the gamma radiation source needed in such demonstrations. To clarify the principles applied in the design of a depth gage, fasten the cobalt 60 capsule to the side of a tall graduate. Cut a hole the size of the capsule in a 2-inch band of lead and wrap it around the graduate. Take a Geiger counter reading across from the capsule. Now gradually fill the graduate and observe the effect on the Geiger counter reading.

For the compactness gage, follow a similar procedure but use iodine 131 and place it near the bottom of the graduate. Fill the graduate with easily compressible materials such as cotton, sponge rubber, or shredded leaves. Take counter readings, with the material in the graduate pressed into various fractions or

FIGURE 30.—Autoradiograph to clarify the electron printing process. Ink was a 10-microcurie per milliliter solution of sulfur 35. Paper disks (upper row) were soaked in 1-microcurie per milliliter solution of phosphorus 32 to show the diffuse effect of a high-energy beta. Circles (lower row) contained a 1-microcurie per milliliter solution of sulfur 35 to show the sharp images produced by a low-energy beta.

multiples of its original volume by removing or adding appropriate quantities.

For the fluid-flow indicator, arrange a long stretch of hose between a water source and discharge sink. Insert the cobalt 60 capsule in the hose next to the water source. Note that a Geiger counter reveals the capsule's location as it passes through the hose.

The electron printing process is an interesting demonstration. Microcurie quantities of long-lived isotopes are added to the ink which is used to produce a master copy. The master copy is then pressed against photographic printing paper. The radiation from the ink registers on the photographic paper which, after development, is an exact reproduction of the master copy. One microcurie per milliliter solutions of sulfur 35 and phosphorus 32 can be used as "inks." The diffuse effect produced by the high energy beta particles from phosphorus 32 can be compared with the sharply defined images from the low energy betas from sulfur 35. Eight to 10 hours of exposure are adequate if no-screen X-ray film is used. Several months' exposure may be required if photographic printing paper is used. By that time the activity of the phosphorus 32 will have decayed to such an extent as to complicate the procedure.

Chapter V

Ideas for Research and Development

Just a few generations ago science teachers, who, in preparation for any original research, wanted to document themselves on their subject, had to read only a few books. They could build most of the equipment necessary for their experiments. Today's science teachers and their students find that extensive reading backgrounds and elaborate equipment are often said to be essential to original research. The history of science shows that the satisfaction a teacher gains from investigating his own hypotheses and those of his students stimulates a powerful enthusiasm in both teacher and students.

The use of radioactive isotopes as tracers is a relatively recent development in science. Elaborate equipment and procedures are not required. Tracers therefore provide an effective method by which teachers and students may test original hypotheses. After a teacher has acquired a working knowledge of radioactive isotopes and their characteristics, one investigation tends to lead to subsequent investigations at a greater rate than time permits completing.

A certain investigation revealed that an additional layer of aluminum foil or cellulose tape produced enough additional shielding effect to cause a shadow on photographic film. It was further noted that low, medium, and high energy beta particles penetrate identifiably different numbers of layers of aluminum foil. Recognizing the similarity to the shielding effect of photographic emulsions, the investigator thought that color film, with its 3-layered emulsion, might produce the equivalent of a color autoradiograph if the test material contained 3 different isotopes with 3 different beta energies.

It was a simple matter to adapt a previous experiment to test the color autoradiograph hypothesis. (The "jumbo" pack of 9 isotopes distributed by one supplier includes calcium 45, sulfur 35, and phosphorus 32. These 3 isotopes yield medium, low, and high energy beta particles.) Individual paper disks were soaked in 1 microcurie per milliliter solutions of the 3 isotopes. These paper disks were glued to a 35-millimeter test card. After this test card had been wrapped with transparent film, it was mounted over the film opening of a 35-millimeter camera. The camera, in turn, was loaded with color film and the various frames were advanced at increasing exposure times. When the film was processed, several of the frames showed only the slightest evidence of success, but it was enough to capture the investigator's enthusiasm. He was led to reexamine the design of his experiment and now awaits an opportunity to test further hypotheses.

Perhaps the questions following this paragraph will lead teachers to make investigations whereby they can experience the satisfaction of formulating their own hypotheses, designing experiments to test them, collecting data and then carrying on from a first-trial investigation to a more fruitful one. If a careful time schedule is arranged and the radioactive material budgeted accordingly, as many as 20 investigations can be carried out with the quantities of radioactive materials included in a single "jumbo" pack. Photographic film is the only really essential equipment, but a Geiger counter adds immensely to the investigator's results and considerably to his peace of mind. (Remember the ground rules for handling nuclear radiations, especially No. 2, p. 31.)

Do germinating seeds take up mineral salts from soil water? How soon after they become moist does the absorption process, if any, occur? How are radioactive materials distributed throughout the tissues of a plant seedling?

Is osmosis a one-way action? Does the rate at which osmosis occurs depend upon the temperature?

In the reaction between barium chloride and sodium chromate, what is the insoluble product?

How completely can iodine be separated from iodine water by shaking with carbon tetrachloride? Ammonium chloride from sodium chloride by fractional crystallization?

Do barium chloride and sodium sulfate diffuse at equal rates through water?

Are plants which absorb the most water from the soil the first to show symptoms of salt "sickness"? If plants which have absorbed radioactive material are transferred to distilled water, will they throw off the absorbed radioactive material?

Are simple animals more likely to avoid a path through a radioactive area than one through a non-radioactive area? Does this imply that those organisms which evolved at a time when the earth's background radiation was higher can detect nuclear radiation and avoid it?

Can isotopes be used to label different plant tissues? If a plant is taken from a solution containing radioactive material, will newly formed tissues be free of radioactive deposits?

Can isotopes be used to check whether or not a plant graft has been successful?

Can isotopes be used to "count" micro-organisms?

Is it possible to cause a spider to deposit radioactive material in its web? Can an autoradiograph of the web be made?

Do albino plants differ from normal plants' absorption of isotopes? How does light affect the absorption of soil minerals?

Can isotopes be used to tag seeds gathered from experimental plants grown with control plants?

Can isotopes be used to compare the water-holding capacity of soils? The erosion rate?

Do aquatic plant and animal forms absorb minerals directly from the water or only through their food?

Do pollen grains which have absorbed a radioactive isotope transfer radioactivity to a plant embryo?

Can an isotope be used to mark the exact instant a plant or animal tissue dies?

Can isotopes be used to check the rates at which fluids move through plant tissues under different conditions?

Can a long-lived isotope be deposited on recording tape for "playback" purposes, using a Geiger counter fitted with an audioamplifier?

Is the conductivity of an electrolyte influenced in any way when the electrolyte is made up from a salt containing a radioactive isotope?

Do ice crystals forming in water "capture" dissolved salts?

Do some ions participate solely as "spectators" in a chemical reaction?

Can a curve that shows the decay rate of a mixture of two isotopes be analyzed to determine the half-lives of the two component isotopes? (The table on p. 20 should allow the student to calculate the curve to be expected from the decay of a mixture containing equal original quantities of iodine 131 and phosphorus 32, for example.)

Can the positive and negative beta particles emitted by zinc 65 be separated in a magnetic field so as to cause separate spots to appear on X-ray film?

Can the effects of toxic materials in weed or insect killers be determined by using isotopes?

Are there identifiable differences in body cells or tissues of irradiated plants and animals?

Can wooden blocks impregnated with iodine 131 be used as controls or to provide additional data when demonstrating the coefficient of friction?

Chapter VI

Social and Economic Implications

Recently, nuclear science has been a factor in social, economic, political, and, in some cases, moral controversies. To present these issues truthfully and without bias is a challenge to all teachers.

High school students want to know whether it is right or wrong to share scientific knowledge with other nations, whether energy sources should be publicly or privately controlled, and whether one nation is justified in contaminating the air above another nation with fallout from nuclear weapon tests.

Examining the social implications of nuclear science calls for techniques by which the teacher can examine critically the events and circumstances under discussion without becoming too closely identified with any one point of view.

Sister Joseph Ann at St. Mary's Cathedral High School in Saginaw, Mich., found panel discussion an effective technique for discussing peacetime uses of radioisotopes, in fields such as medicine, industry, and agriculture.

Don Lindquist, science instructor in the Pontiac, Mich., High School, resorted to a role-playing technique when his students brought up a question that was producing controversy within the community. He set the scene as follows:

> Our scene opens in a middle western city, population about 25,000. This city has three manufacturing concerns, all heavy users of electrical power. The manufacturers have arranged for the community to become a site for a nuclear reactor, and the newspaper has just released the news. Almost everyone is talking about it.

Six roles were played by members of the class. An executive in one of the manufacturing concerns was assumed to be in favor of the reactor. His wife, a clubwoman who, although she confessed that she knew little about reactors, was up to date on gossip. Their daughter, a high school junior, had a limited science background and no opinion on reactors, but had a reasonably open mind. The fourth role was that of a businessman with a knowledge of nuclear energy limited to what he had read in the paper and a fear of contamination from the plant. His wife was deathly afraid of radiation and knew positively that reactors can and very probably would blow up. The sixth role was that of a high school student who had just finished a course in nuclear energy.

Taking his cue from some of the more recent radio and television programs, Fred Moore, instructor in the Owosso, Mich., High School, dramatized interviews with famous scientists. His scripts contained expressions such as:

> Approaching now is the ever-popular teacher, English-American preacher, and member of the Royal Society—John Dalton, . . . And now we have an Englishman, Mr. Electron himself, . . . Dr. Aston, what evidence led you to the discovery of isotopes?

The story of nuclear science has been told many times and many ways. Therefore this publication limits any material of this nature to a chronology of events and observations leading up to our present knowledge about nuclear science (see last section). The chronology may serve as a teaching aid to bring the subject into perspective, to identify elements of it which, if inadequately understood, become stumbling blocks to further understanding, and to show the cumulative progress of the science.

The chronology should lend itself to student assignments such as:

1. Trace the sequence of events which led to the identification and description of the electron.
2. Identify examples of scientists making observations earlier in their work and later used to invent or design something.
3. Prepare a graph or chart showing the rate at which advances in knowledge of nuclear science have progressed and spot basic developments that may have activated sudden spurts forward.

Chapter VII

Protection From Radioactive Fallout: An Instructional Unit

Many science teachers add special meaning to their treatment of nuclear science by presenting a separate unit on protection from radioactive fallout. A sample unit prepared by Jack E. Jines, Santa Fe High School, Whittier, Calif., follows:

Radioactive fallout, sometimes called residual radiation, is a hazard which follows any thermonuclear explosion. Although not more than 15 percent of the fatalities following the A-bomb at Hiroshima were caused by radiation, the problem is increased in H-bomb detonation. The actual danger from fallout depends upon many variables: size and nature of the bomb, height, and meteorological conditions, local topography, and others. Fatalities and sickness from radioactive fallout can be reduced materially if people exercise proper precautions.

Science classes are in a strategic position to teach facts about radioactive fallout. These should include:

1. Nature of radioactive fallout.
2. Effects of it.
3. Methods of protection from it.
4. Methods of decontamination.

This unit is divided into two parts. Part I lists some *typical* facts which students should be expected to derive from a study of radioactive fallout. Part II describes some *demonstrations* to help students to learn and understand these facts.

In the secondary schools of California 45 to 60 percent of the students taking a particular science course do so to meet the science requirement for graduation. Facts about radioactive fallout may well be presented in any science course composed primarily of students who are taking it for this reason. The specific content will vary with the ability and grade level of the students.

Part I—Typical Facts To Be Derived From a Study of Radioactive Fallout

A. *Nature of radioactive fallout*

1. Hazards from radioactive fallout are much greater from ground bursts than from air bursts. Ground bursts from H-bombs produce more fallout than ground bursts from A-bombs. Fallout from the 1954 Pacific tests showered Japanese fishermen 72 miles away.
2. For given areas, fallout patterns vary, since the pattern depends on meteorological conditions as well as the size of the bomb, its design, height, local topography, and other factors. Hazardous conditions may exist in areas more or less than 200 miles from the detonation.
3. Fallout particles may be visible but the radiation from the particles can be detected only with the aid of special devices or instruments.
4. Danger from radioactive fallout is substantially reduced by taking cover. A shelter under 3 feet of earth with properly designed entrance will cut the radiation to about one five-thousandths of that outside; the basement of a house will cut the rate to about one-tenth of that outside.
5. Radiation levels will decrease through the natural decay of the fallout radioactivity.

B. *Effects of radioactive fallout*

1. Biologists do not agree completely on the physiological effects of radiation.
2. The following beliefs, however, are generally accepted:
   a. All radiation is injurious to tissue, but there are commonly accepted safety limits to guide us both in peacetime and after an atomic explosion.[1]
   b. Radiation dosage is cumulative; that is, total exposure must be computed in terms of exposure over a period of hours, days, and years.
   c. Certain tissues are more radiosensitive than others. Radiation damage occurs when the growth and generation of self-replenishing tissues are inhibited in combination with death of cells:
      (1) Bone marrow is especially affected and lack of platelets, a factor in blood coagulation, frequently results from radiation injury.
      (2) Genetic effects, though statistical in nature and remote in time, result from radiation exposure.

[1] Brues, Austin M. Modes of Radiation Injury, *Chemistry*, 29:1:21-30. September 1955. Washington 6: Science Service, 1955.

C. *Protection from radioactive fallout*

1. Best protection is distance from the source.
2. Three feet of earth over a shelter, such as a basement, with windows shielded reduces rate to one five-thousandths of that outside.
3. Emergency cover, such as the basement of the house or unexposed hallways, affords some measure of protection.
4. Any type of cover is better than no cover at all. In an extreme emergency material such as canvas, clothing, and newspapers, can be used to lower exposure rate until better protective cover is available. However, such thin material provides virtually no protection from gamma radiation.
5. Since radiation may continue for hours, days, or even longer, *it is not safe* to leave shelter until civil defense radiological monitors certify the area as safe.
6. Remember that only through the use of special detection devices can one know the intensity of radioactivity, although the fallout particles may be visible.

D. *Procedures for and effects of decontamination*

1. Decontamination means getting rid of matter giving off dangerous radioactivity.
2. Decontamination is a mechanical process. Radioactivity *cannot* be destroyed or neutralized by chemical agents. Boiling, heating, or electrical treatment have no effect. Principal means of decontamination are washing and burying.
3. The procedure for decontamination will vary with the nature of the surface contaminated and the extent of contamination. For example, in some cases hosing down a contaminated surface will be adequate; in others steam or sand blasting may be required, or it may be necessary to remove the substance and bury it deep in the earth.
4. Time will reduce contamination. Natural decay of radioactive materials greatly reduces the hazards of radioactivity.
5. Civil defense radiological monitors will measure the extent of contamination and post areas unsafe to enter.

Part II—Demonstrations To Teach Facts About Radioactive Fallout

To be up-to-date, high school science departments should possess at least one Geiger counter and a cloud chamber. Although commercial models usually give best results, students can build these instruments. The following demonstrations require the use of these radiation detection devices.

A. *Demonstrating nature of radioactivity*

1. To demonstrate the invisible nature of radioactivity, let the students observe two rocks, one containing uranium ore (approximately $3 from standard scientific supply houses) and the other no radioactive material. Place each rock on separate pieces of fast photographic film (use dental X-ray film) in a darkened container such as a desk drawer. After 24 hours remove the film (being careful not to expose to light) and develop it. Let students compare the negatives. What has caused the image on the film under the uranium ore?
2. In a darkened room set up a cloud chamber saturated with methyl alcohol and cooled on a cake of dry ice. The cloud chamber may be either purchased or student-built.[2] Let the students observe the "tracks" formed by the cosmic rays and other radioactivity always present in the atmosphere. Here is an excellent time to point out that small amounts of radioactivity are not harmful. Now let the students observe the increase in the number of "tracks" or "condensations" within the chamber when radioactive ore or other radioactive sources are brought near it. This demonstration shows the invisible nature of radioactivity as well as the ionization power of the rays since the condensations within the chamber result from the formation of ions as the rays shoot through the gases of the chamber.
3. Nature of radioactivity may easily be demonstrated by using a Geiger counter. (Take readings at a given time daily for comparative study. This would be especially interesting during periods of atomic testing at the Nevada Proving Grounds.) The radioactivity of such articles as luminous paints and watch dials can be shown. With a sensitive Geiger counter, demonstrate more technical aspects of the nature of radioactivity. Some examples are: (a) effect of distance away from source (varies inversely as the square of the distance); (b) effect of decay or half-life (using a source such as phosphorus 32, radioactivity can be measured at definite time intervals). Now plot a graph, using intensity against time, which will show that intensity drops sharply at first and then tapers off more slowly.[3]

B. *Effects of fallout.*[4] (No demonstrations.)

C. *Protection against fallout.*

Radiation that emanates from fallout has differing penetrating powers. Alpha has a very short range, and gamma the greatest penetrating power. Using radio-

[2] For details of construction, see *Laboratory Experiments with Radioisotopes for High School Science*, p. 15–16. Washington: U. S. Government Printing Office, 1953. 30 cents. A chamber with instructions and radioactive sources may be purchased from the Atomic Laboratories, Inc., P. O. Box 343, Berkeley, Calif.

[3] A radioactivity demonstrator, "Classmaster," produced by the Nuclear Instrument and Chemical Corporation, Chicago, Ill., is useful for many different demonstrations. The particular Geiger counter used in class should, in any event, include the beta window and metal shield for alpha particles, and give readings in counts/minutes. Small vials containing solutions of 10 microcuries of radioactive isotopes such as P^{32} and I^{-131} may be obtained from commercial laboratories. Ten microcuries are relatively inexpensive and are safe for classroom use.

[4] *Laboratory Experiments with Radioisotopes for High School Science*, ibid.

active sources such as I^{131} for gamma radiation, or P^{32} for beta radiation, it is possible to study relative effects of various types of shielding. The great energy imparted by A-bombs and H-bombs cannot (and should not) be duplicated in high school laboratories, but the results obtained by using the sources named above will illustrate effects of shielding.

To study relative effects of shielding the following procedure is suggested:

Materials:

1. G–M tube and counter.
2. Radioactive source such as P^{32}, I^{131}, or uranium ore.
3. Shielding such as newspapers, a wooden box, concrete blocks, assorted pieces of metal, and some soil.

Method:

1. With the Geiger counter record the background rate.
2. Mount the G–M probe in a fixed position so that equal distance can be maintained from the source and shielding throughout the tests.
3. Mount the radioactive source in a fixed position and measure the counts/minutes with *no shielding*.
4. Next check the effects of shielding, using some of the following:
   - Newspapers—single sheet.
   - Newspapers—multiple sheets.
   - Aluminum or other metal squares of uniform thickness and density.
   - Wooden box (can simulate hallway of a frame house).
   - Wooden box—surrounded by concrete blocks (simulated basement, etc.).
   - Wooden box—surrounded by concrete box, covered with soil (simulated basement shelter).

It should not be assumed that radiation could be reduced as effectively from a thermonuclear bomb as that from the small sources used in this demonstration. However, the basic principles of shielding can be illustrated and gamma radiation can be shown to have much greater penetrating power than either alpha or beta radiation.

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Most of the entries concern new ways to teach the nuclear science story and are divided into 5 groups. The first 3 groups list readings for elementary grades, high school, and college, with the high school predominating. The fourth group gives a list of basic texts and the fifth, a list of readings on various phases of radioactivity.

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Films

The following descriptive list of films [1] about nuclear science is presented alphabetically by title. A representative list was compiled by a group of Michigan science teachers working in the pilot center set up in that State to help carry out the activities forming the background for the present text.

"A" Is for Atom.—15 min., 16 mm., sd., col. Not for sale. Loan from General Electric Co., Schenectady 5, N. Y., or Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Youth, adults.

An animated cartoon explaining atomic structure, nuclear fission, and peacetime applications of the atom.

Atoms and Agriculture.—12 min., sd., b & w. 1954. Purchase price $50, rental $2.50 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Avenue, Wilmette, Ill. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: School, college, adults.

Reveals the areas in which radioactivity can be expected to play a part and produce results for agriculture. Tells the story of how radioactive isotopes are employed as tracers to aid science in meeting agricultural problems, including food problems, and how radioactivity aids genetic and growth studies. (Library of Congress catalog card number Fi 54–6.)

Atom and Biological Science—10 min. Rental $1.75. Encyclopedia Britannica Films, Inc., 1150 Wilmette Avenue, Wilmette, Ill. Use: Biology, chemistry, clubs, general science, physics.

Shows biological effects of high energy radiation, current beneficial uses of this radiation, precautions against harmful effects, different types of high energy radiation, and essential similarity in effects of each on varied organisms.

Atoms and Industry.—11 min. Rental $1.75 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Avenue, Wilmette, Ill. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Chemistry, physics, science clubs.

Presents isotope applications in oil, automotive, and paper industries. Measurement of wear on moving parts and paper thickness.

Atom and Medicine.—12 min. Rental $1.75 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Avenue, Wilmette, Ill. Use: Chemistry, nursing, pharmacy, physics.

Important role of radioisotopes in hospitals, clinics, and doctors' offices. Clarifies misconceptions about alleged dangers of radioisotope diagnosis and therapy. Describes some of the instruments and devices used to handle radiation safely.

Atom and the Doctor.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Pictures thyroid and leukemia tests. A sequence taken at the Oak Ridge Cancer Hospital shows applications of the atom in medicine.

Atom and the Weather.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

Illustrates why tests of atomic weapons have no effect on the weather, how radioactive fallout is carefully traced to protect the public, and how radioactivity from atomic tests is used as a research tool by the weatherman.

Atom and You.—16 min., sd., b&w. 1954. Purchase price $50 from Paramount Newsreel Inc., 544 W. 43d St., New York 36, N. Y. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Newsreel footage at Atomic Energy Commission installations. Shows the uses of radioisotopes in biology, medicine, agriculture, and industry, and the development of atomic power.

Atom Goes to Sea.—12 min., sd., b&w. 1954. Purchase price $20 or free loan from General Electric Co., Schenectady 5, N. Y. Use: Junior and senior high school, college, adults.

Within the limits of military security, the film explains how an atomic-powered submarine operates. Includes scenes of work by General Electric Company engineers at the Knolls Atomic Power Laboratory in Schenectady and the submarine reactor test site at

[1] The following abbreviations are used in the descriptions: *min.*—running time in minutes; *mm.*—millimeter width of film; *sd.*—film has a sound track; *silt.*—silent film; *b&w.*—black and white film; *col.*—color film.

West Milton, N. Y. (Review: Business Screen, No. 6, vol. 15, 1954, p. 36.)

Atom Atoll.—18 min., sd., b&w. 1953. Free loan from Signal Office, Fifth Army, 1660 E. Hyde Park Blvd., Chicago 15, Ill. Use: School, college, adults.

Portrays a joint task force on Eniwetok making preparations for atomic test explosions and waiting for the explosion; and the explosion itself. (Library of Congress catalog card number Fi E 54–422.)

Atoms for Peace: Part 1—Introducing the Atom.—21 min., sd., b&w. 1955. Purchase price $45.36 from United World Films, Inc., 605 W. Washington Blvd., Chicago 6, Ill. Use: School, college, adults.

Produced by Warner News for U. S. Information Agency. Explains the nature of the atom and of atomic energy; demonstrates through animation the make-up, function, formation, and control of chain reaction; and indicates potential uses of atomic material in medicine, agriculture, and industry. (Library of Congress card number Fi E 56–15.)

Atom Smashers.—12 min., sd., b&w. 1953. Purchase price $50, rental $2.50 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: Junior and senior high school, college, adults.

Explains the importance of cyclotrons and describes two other major types of atom smashers—linear accelerators and betatrons. (Library of Congress catalog card number Fi 54–4. Review: Film World, December 1953, p. 767.)

Atom Smashers.—12½ min., sd., b&w. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Explains the principle of atom smashers. Shows the cyclotron, synchrotron, and cosmotron in operation and the actual smashing of the atom. (Review: Film World, June 1954, p. 364.)

Atomic Alchemist.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Shows some of the new facets opened by the atom to the chemist who can now fulfill the dream of the alchemist and create new elements.

Atomic Age Farmers.—12½ min., sd., b&w. 1955. Rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

Produced with the technical assistance of the U. S. Atomic Energy Commission and the Atomic Energy Project at the University of California, Los Angeles. Three applications of atomic energy in agriculture: mutation of corn, animal studies, atomic tracers farm.

Atomic Alert.—10 min. Rental $1.75 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: Youth and adults.

An atomic bomb explodes with usual explosive elements of blast and heat, plus release of radioactivity. Home basement shelter equipped with a survival kit; children at school during atomic attack; how they should act. Avoids scare mood.

Atomic Biology for Medicine.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

Explains various research experiments in biomedicine using atomic energy as an effective tool. Dust inhalation tests made with animals at the Atomic Energy Project at U. C. L. A will help to protect workers in the atomic energy industry. At Oak Ridge the eyes of mice are examined for effects of radiation. Animals are used to study the effects of radiation on cell division, bones, other tissue, and tumors.

Atomic Bomb—Its Effects and How To Meet Them.—50 min., sd., b&w. 1953. Purchase price $150, rental $6 from British Information Service served by Film Centre, Inc., 64 W. Randolph St., Chicago 1, Ill. Use: School, college, adults.

A step-by-step account through the use of live presentation, drawings, symbols, and models of what would happen to a city and its population should an atomic bomb be detonated 1,000 feet above the city, and the civil defense problems which would result.

Atomic Cities.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

Produced with the assistance of the Atomic Energy Commission. Safety measures have had to be devised to safeguard the atomic worker and his family from stack gases, waste, and other potential hazards caused by radioactive materials.

Atomic Detective.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

This film describes the various types of radiation counters, including the Geiger counter, from small hand units to large installations; and illustrates how they are used in industry, hospitals, research laboratories, and uranium prospecting.

Atomic Energy.—11 min. Rental $1.75 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: General science, chemistry, physics, clubs.

Select this film with care. Opening and closing shots are of Bikini test; body of film describes in complete, animated sequences the principles of nuclear fission and chain reactions. Leisurely paced, but great concentration and restudy are necessary for full understanding. Excellently organized, highly graphic, completely visualized.

Atomic Furnaces.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose

Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Explains the principle of atomic reactors and demonstrates their operation in such installations as Brookhaven, Oak Ridge, and Los Alamos. (Review: Film World, April 1954, p. 242.)

Atomic Greenhouse.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C.

Illustrates the process of using radioisotopes to trace fertilizer absorbed from the soil into a plant to determine more efficient uses of fertilizer.

Atomic Metallurgy.—12½ min., sd., b&w. 1955. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: School, college, adults.

Produced with the assistance of the Atomic Energy Commission. Powerful radiation and extremely high temperatures in the new atomic furnaces require development of metals which can hold up under those unprecedented conditions. Film explains how progress in our atomic age is dependent on metallurgy.

Atomic Pharmacy.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Shows the handling by remote control of highly radioactive liquid materials and the preparation and shipping of a radioactive prescription.

Atomic Physics.—90 min., 16 mm., sd., b&w. Purchase from United World Films, Inc., 1445 Park Ave. New York 29, N. Y., or free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Produced by the J. Arthur Rank Organization, Ltd., released in the U. S. by United World Films, Inc. NOT cleared for television.

An authoritative technical film in five parts on the history and development of atomic energy.

Atomic Radiation.—12 min., sd., b&w. 1954. Purchase price $50, rental $2.50 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: School, college, adults.

Explains the fundamentals of atomic radiation, its discovery, what it is and does, and why it should be respected rather than feared. Describes how it has been possible to reproduce in the laboratory some of the forms of radiation found in nature. Explains the roles of alpha, beta, gamma, and neutron particles in radioisotope research.

Atomic Research: Areas and Development.—13½ min., sd., b&w. 1953. Purchase price $68.75 from Coronet Instructional Films, 63 E. South Water St., Chicago 1, Ill. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: School.

Authentic footage of actual research installations and operations. Surveys three large areas of atomic research—the energy applications of nuclear fission, structure of the atom, and byproducts of nuclear fission. (Library of Congress card number Fi 53–367. Review: Film World, December 1953, p. 767.)

Atomic Tests in Nevada.—25 min., sd., b&w and color. Purchase price for b&w, $28.94; color, $129.61 from Lookout Mountain Laboratory, 8935 Wonderland Ave., Hollywood 46, Calif. Produced by U. S. Atomic Energy Commission. Use: Junior and senior high school, college, adults.

Describes the testing of atomic weapons at the AEC's Nevada Test Site, with emphasis on measures to protect the public. (Library of Congress catalog card number Fi E 56–135.)

Atomic Zoo.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Studies how radioactive materials affect sheep and fish in relation to human consumption; gives an analysis of egg formation.

Canada's Atom Goes to Work.—11 min., sd., b&w. 1950. Purchase price $30 from National Film Board of Canada, 630 Fifth Ave., New York 20, N. Y. Use: School, college, adults.

A progress report on nuclear research conducted at the atomic energy plant at Chalk River, Ont., and on some of the constructive applications of atomic energy carried out in hospitals (including the "cobalt bomb" in cancer treatment), in agricultural experimental stations, and in industry. Interior views of the Chalk River plant afford a look at NRX, the atomic pile itself. A brief survey is made of atomic research in Canadian universities. (Library of Congress card number Fi A 52–1097.)

Carbon Fourteen.—12 min., sd., b&w. 1954. Purchase price $50, rental $2.50 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: School, college, adults.

Explains the use of radiocarbon (carbon 14) as a means of determining the age of historic and prehistoric objects. Shows how it is being used to study the process of photosynthesis and describes experiments at the Argonne National Laboratory to study the effect of radiation upon plants. (Library of Congress card number Fi 54–5.)

Dawn's Early Light.—30 min., sd., col. 1955. Purchase price $160 or free loan from Westinghouse Electric Corp., Film Division, Box 868, 401 Liberty Ave., Pittsburgh 30, Pa. Use: College, adults.

Filmed by Roland Reed Productions with the technical assistance of the United States Atomic Energy Commission and the Department of Defense. After a high school senior reads a frightening article on atomic energy, his father, a scientist, explains several benefits of atomic energy. They watch a working

model of an atomic reactor, which an engineer explains in simplified terms. The father traces the development of atomic power from the first atomic pile to the submarine Nautilus and the atom's peacetime future in generating electricity.

Electrons.—11 min. Animation. Rental $1.75 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: General science, industrial arts, physics.

Hypothesis that electricity consists of unit elementary charges is supported by observation of phenomena associated with the conduction of electricity in liquids, gases, and vacuum. Phenomena and principles explained: Faraday's laws, valence, Millikan's oil drop experiment, principles of vacuum tubes, Edison effect photo-electric cells, reproducing sound on film, determination of the electron's mass.

Energy from the Sun.—11 min., sd., b&w. Purchase price $50, rental $2.50 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: Junior and senior high school.

Telescopic stop-motion photography made at the High Altitude Observatory at Climax, Colo., over a number of years reveals violent eruptions near the sun's surface which eject solar matter millions of miles. Animation shows how solar energy is transmitted through space and why the earth receives so small a fraction. In simple terms, the film illustrates how the fusion of hydrogen nuclei forms helium nuclei, and how some of the mass, which appears lost, is converted into energy. (Library of Congress card number Fi 55-100.)

Engineering for Radioisotopes.—21½ min., 16 mm., sd., b&w. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C.

Produced by the Oak Ridge National Laboratory for the U. S. Atomic Energy Commission by a division of the Union Carbide and Carbon Corporation. Describes the chemical, mechanical, electrical, and construction engineering skill required to put production and processing of radioisotopes on an efficient, industrial basis.

The Eternal Cycle.—12½ min., 16 mm., sd., b&w. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Not cleared for television except by special permission of the producer.

One of 13 pictures in *The Magic of the Atom* series. Shows how the products of atomic energy are used for biological research—illustrating how radioactive materials move from soil to plant to test animal in biological cycling.

Fundamentals of Radiac Instruments.—25 min., sd.' b&w. 1955. Free loan from U. S. Army, Commanding General, Attention: Signal Officer, Fifth Army, 1660 E. Hyde Park Blvd., Chicago, Ill. Purchase price $44.64 from United World Films, Inc., 605 W. Washington Blvd., Chicago 6, Ill. Use: School, college, adults.

Reviews basic atomic theory. Explains radiac instruments, including film badge, film ring, pocket dosimeter, and pocket chamber; and intensity devices such as scintillation detector, ionization chamber, proportional counter, and Geiger-Mueller counter. (Library of Congress card number Fi E 55-355.)

H-Bomb.—3½ min., slt., b&w or col. For purchase price write to World in Color Productions, 108 W. Church St., Elmira, N. Y. Use: Elementary school, junior and senior high school, college, adults.

Photographs of the 1952 hydrogen bomb tests made on islands in the Pacific. (Library of Congress catalog card number Fi A 54-4020.)

House in the Middle.—12 min., sd., col. Request your local civil defense director to order this film on free loan from the Michigan Office of Civil Defense. Purchase price, b&w, $15.23; color $41.70 from Capital Film Laboratories, 1905 Fairview Ave. NE., Washington 2, D. C. Use: Senior high school, college, adults.

Shows three small houses used in official fire tests at the Atomic Energy Commission's Nevada Proving Ground in 1955. The house in the middle withstands the fire effects of the atomic burst because it is free of litter and trash, properly painted, and made of good materials. The houses at either side of it are completely destroyed by fire as a result of their run-down, badly weathered condition, and the trash accumulation around one of them. The value of good household fire prevention habits is brought home to the viewer in a dramatic stop-motion sequence made during the actual atomic test explosion.

Industrial Atom.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

Produced with the technical advice of the Atomic Energy Commission and the University of California at Los Angeles. The film illustrates various ways in which the petroleum industry is applying atomic energy; including radioactive piston rings to determine the quality of oils, an atomic source and a radiation counter to locate a scraper stuck in a pipeline, and atomic tracers to pinpoint leaks in pipes embedded in cement. (Review: Film World, February 1956, p. 98.)

An Introduction to Radiation Detection Instruments.—15 min., sd., b&w. Request your local civil defense director to order this film on free loan from the Michigan Office of Civil Defense. Use: Senior high school, college, adults.

This film, made for the Armed Forces Special Weapons Project, shows the methods of monitoring, the use of protective clothing, and the process of decontamination. The radiation detection instruments portrayed are those that were available in 1950.

Jobs in Atomic Energy.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

The film shows the vast diversification of employment opportunities created through the development

of atomic energy. We see scientists, technicians, and laborers at work all over the country in atomic research, power production, industrial applications, agriculture, medicine, and many others. (Review: Film World, April 1956, p. 109.)

Linear Accelerator.—12 min., sd., b&w. 1955. Purchase price $67.50, rental $2.55 from British Information Service, served by Film Centre, Inc., 64 W. Randolph St., Chicago 1, Ill. Use: School, college, adults.

The film introduces the theory of nuclear transmutations and describes the production of hard X-rays with laboratory accelerated particles. The development of equipment and technique is traced from the Cockcroft and Walton experiments to a 4-Mev linear accelerator used in a hospital to treat malignant tumors. This type of radiation is explained as having a much greater depth of penetration than ordinary deep therapy.

Master Slave.—12½ min., sd., b&w. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Demonstrates the remote control apparatus which makes it possible to manipulate highly radioactive materials from a safe distance.

Nuclear Reactor.—9 min., sd., b&w. 1954. Purchase price $40 from McGraw-Hill Book Co., Text Film Dept., 330 W. 42d St., New York 18, N. Y.

Explains nuclear stability and neutron-induced fission; then neutron emission, the self-sustaining chain reaction, and the role of the moderator. Illustrates the application of these ideas to the pile and pictures the production of plutonium and tracer elements.

Nuclear Reactors for Research.—20 min., sd., col. 1954. Free loan from North American Aviation, Inc., 12214 Lakewood Blvd., Downey, Calif. Use: School, college, adults.

Describes a solution-type nuclear reactor recently designed and developed by North American Aviation, Inc. Shows how the reactor has been specially engineered for widespread peacetime application in medical, academic, and industrial research. Safety features for the protection of personnel and equipment are pointed out. An animated sequence demonstrates the process of splitting the atom to release its energy. (Review: Film World, June 1955, p. 318.)

Operation A-Bomb.—16 min., sd., col. 1954. Produced by RKO Pathe. Purchase price $180 from McGraw-Hill Book Co., Text Film Dept., 330 W. 42d St., New York 18, N. Y. Use: Junior and senior high school, college, adults.

The actual story of an A-bomb operation filmed in the Nevada desert photographed by U. S. Marine Corps cameramen. Atomic warfare maneuvers are shown. Pictures the actual explosions, the mushrooming clouds, the damage resulting, and inspection of the area by Marine Corps radiological teams.

Operation Crossroads.—27 min., 16 mm., sd., col. Free loan from District Public Information Officer, Ninth Naval District, U. S. Naval Training Center, Great Lakes, Ill., or Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C.

An official Navy film, in full color, of the two Bikini test explorations and the preliminary preparations.

Operation Greenhouse.—25 min., sd., col. 1952. Produced by the U. S. Atomic Energy Commission. Purchase price $140.23 from United World Films, Inc., Govt. Films Dept., 605 W. Washington Blvd., Chicago 6, Ill. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: School, college, adults.

Describes the scientific and technical operations of the Atomic Energy Commission during the nuclear weapons tests at Eniwetok in the spring of 1951. Depicts blast and thermal effects of the explosions on different types of structures. (Library of Congress catalog card number Fi E 53–131.)

Operation Hurricane.—27 min., sd., b&w. 1953. Purchase price $75, rental $3.75 from British Information Service, served by Film Centre, Inc., 64 W. Randolph St., Chicago 1, Ill. Use: School, college, adults.

In October 1952, a British-made atom bomb was exploded inside a ship off the island of Monte Bello on the Australian coast. This film describes what happens when an atom bomb test is made—the elaborate arrangements to record the results of the explosion, the awesome suspense of waiting for the great experiment to take place, the explosion itself, and the cautious return of the scientists and naval and military observers to the devastated island.

Operation Ivy.—28 min., sd., b&w. 1954. Purchase price, b&w, $27.90; color, $84.55 from Capital Film Laboratories, 1905 Fairview Ave., N. E., Washington 2, D. C. Request your local civil defense director to order this film on free loan from the Michigan Office of Civil Defense.

A documentary on a thermonuclear test at the AEC's Pacific Proving Grounds in 1952, with introductory remarks by President Eisenhower and a closing statement by former FCDA Administrator Val Peterson.

Our Atomic Development.—26 min., sd., b&w. 1953. Purchase price $100 from McGraw-Hill Book Company, Text Film Dept., 330 W. 42d St., New York 18, N. Y. Use: School, college, adults.

Produced by March of Time for television. Traces the growth and the present extent of the atomic energy program including atomic plants, location of uranium ore, and development of new bombs and weapons. (Library of Congress catalog card number Fi 53–168.)

Our Friend the Atom.—60 min. Produced by Walt Disney Productions, Hollywood, Calif. Narrated by Heinz Habner. Use: Youth, adults.

Shows how knowledge of the atom's energy finally emerged as a result of the efforts of the great minds of the past who have contributed to our atomic science of today. The atom is easily understood through a clear and fascinating presentation. Youth and layman alike will be able to understand what to expect for the future of the world.

Our Mr. Sun.—60 min., sd., col. Produced by American Telephone and Telegraph Co. Free loan from business office of your local telephone company. Since this film is in great demand, allow one month in booking your request. Use: Youth, adults.

A unique tale-telling technique is used in which Research shows how modern man has learned many secrets about Our Sun, including evidence to support the idea of nuclear fusion as a continuous sun process.

Power Unlimited.—12½ min., sd., b&w. 1955. Rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: School, college, adults.

Explains how electricity is produced from the atom. Most of the film is taken at the Atomic Energy Commission's experimental breeder reactor in Idaho, the first atomic furnace to generate usable electricity. This reactor "breeds" atomic fuel while producing electricity.

Primer on Monitoring.—30 min., 16 mm. sd., col. Produced by the University of California (Los Angeles) film department. Purchase price $122 from the department. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Cleared for television.

Describes basic principles of radiation monitoring.

Protecting the Atomic Worker.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. Use: Junior and senior high school, college, adults.

Shows the many safeguards employed to protect the men and women who work closely with dangerous radioactive materials.

Radioactive Series.—9 min., sd., b&w. 1954. Purchase price $40 from McGraw-Hill Book Co., Text Film Dept., 330 W. 42d St., New York 18, N. Y. Use: Senior high school, college.

Traces the various stages in the decay of U^{238} to stable lead. Alpha emission, beta emission, and the statistical nature of the process are emphasized. A brief mention is made of other radioactive series.

Radiation—Silent Servant.—12½ min., sd., b&w. 1955. Purchase price $55, rental $10 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Use: Junior and senior high school, college, adults.

Depicts four examples of controlled radiation as an important help in diversified fields. A cobalt source at Brookhaven bombards plants to aid studies in plant genetics that may lead to better strains of food crops. An atom smasher (accelerator) directs a beam of subatomic particles against a test animal to aid studies of the treatment of deepseated tumors. A patient at the Brookhaven Cancer Research Hospital is treated for a cancer of the thyroid with the help of radioactive iodine. The final sequence deals with the Medical Research Reactor at the University of California, Los Angeles, and the possible treatment of brain tumors.

Radioactive Contamination.—18 min., sd., b&w. 1952. Purchase price $29.11 from United World Films, Inc., Government Films Dept., 605 W. Washington Blvd., Chicago 6, Ill. Use: School, college, adults.

Produced for the U. S. Department of Defense. Portrays two shipyard workers expressing fear of radioactive contamination of U. S. S. *Independence* after Bikini atomic bomb tests. Explains that radioactive contamination is only one of the effects of atomic bomb explosions and illustrates methods used in decontamination of radioactive elements. Produced under the supervision of the Armed Forces Special Weapons Project. (Library of Congress card number Fi E 53-536.)

Radioisotopes in Agricultural Research.—41 min., sd., b&w. 1953. Purchase price $59.64 from United World Films, Inc., Government Films Dept., 605 W. Washington Blvd., Chicago 6, Ill. Produced by the U. S. Army. Use: School, college, adults.

Explains the use of radioisotopes in agricultural research. Traces the utilization of chemicals by plants and animals and explains how the exact amounts needed are determined by radioactive chemicals. Shows the manufacture of radioactive phosphate and experiments using radioactive phosphate in fertilizer and radioactive cobalt in livestock. (Library of Congress catalog card number Fi E 53-494.)

Report on the Atom.—19 min., 16 mm., sd., b&w. Rental $3.40 from March of Time, Forum Edition, 369 Lexington Ave., New York 17, N. Y. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. NOT cleared for television.

Produced by the March of Time as a regular release.

Radiological Survey.—21 min., sd., b&w. 1952. Purchase price $32.54 from United World Films, Inc., Government Films Dept. 605 W. Washington Blvd., Chicago 6, Ill. Produced by the U. S. Department of Defense. Use: School, college, adults.

Portrays a simulated underwater explosion of an atomic bomb near the coast, the radioactive fog created and spread inland over a 10-mile area, and the aerial and ground crews of the radiologically contaminated area. Produced under the supervision of the Armed Forces Special Weapons Project. (Library of Congress catalog card number Fi E 53-537.)

Report on the Atom.—19 min. Rental $3.25 from McGraw-Hill Book Company, Text Film Dept., 330 W. 42d St., New York 18, N. Y. Use: General science, physics, social science.

Portrays mining of uranium, manufacture of radiomaterials (isotopes), studies conducted on exposure effects and on commercial uses, protection for workers and populace, and covers the question of how much secrecy is needed.

Security.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C.

Illustrates the various ways in which atomic plants are protected.

Speed of Light (Measurement and Application).—14 min. Rental $2 from Encyclopedia Britannica Films, Inc.,

1150 Wilmette Ave., Wilmette, Ill. Use: Astronomy, natural science, physics.

Contributions of Galileo, Fizeau, Roemer, and Michelson to measurement of speed of light. Important applications of this constant today. Animation of Michelson's famed experiment (a cycle of light flashes between Mt. Wilson and Mt. San Antonio).

Tagging the Atom.—12½ min., sd., b&w. 1954. Purchase price $55 from Handel Film Corp., 6926 Melrose Ave., Hollywood 38, Calif. Limited loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C.

Illustrates manufacture of radioisotopes.

Tale of Two Cities.—20 min., 16 mm. or 35 mm., sd. Free loan from Signal Office, Fifth Army, 1660 E. Hyde Park Blvd., Chicago 15, Ill.

This film presents the destructive results of the bombings of Hiroshima and Nagasaki. Many close-up scenes show the effects on buildings and materials.

Target Nevada.—16 min., 16 mm., sd., col. Produced for the U. S. Air Force by Lookout Mountain Laboratory, 8935 Wonderland Ave., Hollywood 46, Calif. Free loan through all Air Force libraries, the U. S. Atomic Energy Commission, and its field offices. Cleared for television.

Depicts Air Force participation in tests at the AEC test site.

Ultimate Structure.—40 min., sd., b&w. Free loan from North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y. Use: College, adults.

Clearly outlines how instruments identify and measure elements and compounds through analysis of atomic structure. Wave motion and crystal theories are demonstrated to illustrate research and production control applications in industry.

Unlocking the Atom.—20 min., 16 mm., sd., b&w. Purchase price $95 from United World Films, Inc., 1445 Park Ave., New York 29, N. Y. Free loan from Public Information Service, U. S. Atomic Energy Commission, Washington 25, D. C. NOT cleared for television.

Produced primarily to acquaint students with the principles that govern the atom and its use. Describes chain reaction, atomic structure, properties of alpha, beta, and gamma rays, operation of cyclotron, and contributions of various scientists.

Uranium, New American Frontier.—13 min., sd., col. 1955. Free loan from Modern Talking Picture Service, Inc., 45 Rockefeller Plaza, New York 20, N. Y. Use: Junior and senior high school, college, adults.

Sponsored by Precision Radiation Instruments, Inc. Produced by Color Reproduction Company. Tells the amateur all he needs to know about uranium prospecting. Outlines the importance of uranium in the national defense and as a source of commercial power. Describes uranium distribution and sources, how to file a claim, payments made by the Atomic Energy Commission, informational aids from government agencies, and kinds of equipment needed.

Using Atomic Energy for Electric Power.—Filmstrip. Produced by Film Strip-of-the-month Club, Inc., 353 4th Avenue, New York 10, N. Y. Use: Junior and senior high school. Lecture notes provided.

What is electricity?—17 min. Rental $2.75 from Encyclopedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill. Use: General science, natural science, physics.

Nature of electricity and historical discoveries leading to our understanding of it. Contributions of Franklin, Faraday, and others over several centuries. Action of electrons within elements and relationship of this action to the flow of electricity.

Chronology of Steps Leading to Our Present Knowledge About Nuclear Science

One of the most brilliant periods in science reached its climax when 20th-century scientists finally put together a picture of the atom—a picture sufficiently clear and accurate to allow them to bring under control the enormous energies involved in atomic phenomena.

Man's understanding of atomic structure and nuclear energy has been developed from thousands of individual observations and hypotheses and the discoveries resulting from them. For each person whose contribution is noted in the chronology that follows, there were and are thousands of others who have made important contributions not publicly recognized.

This chronology is designed to help teachers and students put the whole subject of atomic energy in perspective and to comprehend its evolutionary nature.

550 B. C. The word "atom" used to describe the part which remains after something can no longer be divided. *Democritus*

1575 The word "electricity" used to describe the property exhibited by amber upon being rubbed with fur. *W. Gilbert*

1661 Elements defined as those substances which have distinct properties and from which compounds can be made. *R. Boyle*

1705 Light is emitted when amber is rubbed in a closed vessel from which the air has been removed. *F. Hauksbee*

1733 There are two kinds of electricity—vitreous and resinous. *C. F. Dufay*

1747 Electricity seems to come in positive and negative forms but this may be due to an excess or deficiency of electrical fluid. *B. Franklin*

1752 Electricity passes more readily through a tube after it has been evacuated and its passage is accompanied by a luminous glow. *W. Watson*

1780 Animals produce a dynamic type of electricity. *L. Galvani*

1796 The essential factor in producing "animal" electricity seems to be two different metals separated by wet pasteboard or leather. *A. Volta.*

1808 Substances seem to be made up of tiny particles which, for any given element or compound, are alike in size, shape, and weight; are not changed but are rearranged during chemical reactions; and combine in small whole number ratios to form compounds. *J. Dalton*

1811 Equal volumes of different gases under the same pressure and temperature contain equal numbers of molecules. *A. Avogadro*

1816 The atomic weights of each of the elements must be whole number multiples of that of hydrogen. *W. Prout*

1816 By comparing the density of steam with that of water, a molecule of water must have a diameter of about 10^{-9} inch. *T. Young*

1828 Microscopic particles suspended in water show random and haphazard movement. *R. Brown*

1833 "Animal" or dynamic electricity seems to be simple static electricity in motion. *M. Faraday*

1834 A given quantity of electricity passing through a solution always sets free at the electrodes chemically equivalent weights of different substances. *M. Faraday*

1847 Although one form of energy may be converted into another form, it can neither be created nor destroyed. *H. von Helmholtz*

1858 Just as atoms are the smallest possible portions of elements, so are molecules the smallest possible portions of compounds. *S. Cannizzaro*

1862 The green glow near the cathode of a discharge tube can be moved with a magnet. *J. Plucker*

1869 Certain properties of the elements are a periodic function of their atomic weights. *D. I. Mendelyeev*

1874 Arguing from Faraday's observation, electricity must come in single, definite units. *G. J. Stoney*

1876 Cathode rays travel in straight lines. *H. Geissler*

1883 A moving charged particle can be deflected from its path by either an electric or magnetic field. *H. Hertz*

1885 Cathode rays consist of a stream of negatively charged particles. *W. Crookes*

1886 Rays (canal) appear behind a perforated cathode. *E. Goldstein*

1887 The speed of light does not depend upon whether it is moving parallel or perpendicular to the earth's motion through a hypothetical ether. *E. W. Morley and A. A. Michelson*

1890 So-called cathode rays from discharge tubes can produce shadow photographs of ordinarily opaque objects. *A. W. Goodspeed*

1891 The elementary unit of electricity may be called an electron. *G. J. Stoney*

1893 Differences in the speed of light moving with or against the flow of the ether cannot be detected because of instrument defects. *C. F. Fitzgerald*

1894 Canal rays can form shadow photographs. *P. Lenard*

1895 Canal rays carry positive charges. *J. Perrin*

1895 A sheet of paper coated with barium platinocyanide glows brilliantly when near a discharge (X-ray) tube. *W. C. Roentgen*

1896 Dust-free air will, if saturated, fog up when exposed to X-rays or rays from uranium. *C. T. R. Wilson*

1896 A strong magnetic field splits spectral lines as though the specific charge on an electron is 5.273×10^{17} e. s. e./gram. *P. Zeeman*

1896 Crystals of uranium salt emit radiation capable of penetrating opaque materials, affecting photographic film, and discharging electroscopes. *H. A. Becquerel*

1897 The unit charge on a cloud particle is equal to that on a gaseous ion. *J. S. Townsend*

1898 Gaseous ions produced by X-rays carry the same unit of charge as do cloud particles or ions from other sources. *J. J. Thomson*

1898 Since all unit charges of electricity seem to have the same charge/mass regardless of where they occur, there must be a thing we will call the "electron." *J. J. Thomson*

1898 Canal ray particles are much heavier than cathode ray particles. *W. Wein*

1898 The ray-emitting property of uranium is radioactivity. *M. Curie*

1898 The atom seems to contain a large number of corpuscles with their negative charges balanced by an equal amount of positive charge. *J. J. Thomson*

1898 All compounds of uranium seem to be radioactive and, in general, the activity is greater the more uranium they contain. *M. Curie*

1898 Two uranium minerals, pitchblende and chalcolite, are much more active than uranium itself. *M. Curie*

1898 A heretofore unknown metal (plutonium) with activity 400 times greater than that of uranium can be isolated from pitchblende. *M. and P. Curie*

1898 Pitchblende contains another strongly radioactive substance (radium) which is like barium but has 900 times the activity of uranium. *G. Bemont and P. and M. Curie*

1899 Substances placed near radium acquire an induced or excited radioactivity. *M. and P. Curie*

1899 Rays from radioactive substances can be deflected by a magnetic field. *H. A. Becquerel, S. Mayer, E. von Schweidler, and F. Giesel*

1899 Some radiation from uranium will penetrate only 0.002 cm. of aluminum while another variety (beta) will pass through much thicker sheets. *E. Rutherford*

1900 Some uranium radiation is deflected by a magnetic field and some not. *P. Curie*

1900 Rutherford's penetrating rays are the ones that can be deflected by magnetic and electrical fields. *E. Dorn*

1900 Beta radiation carries negative charges. *M. and P. Curie*

1900 Beta radiation has the same charge/mass ratio as cathode rays. *H. A. Becquerel*

1900 Radioactive materials emit a third kind of radiation (gamma) that has great penetrating power, affects photographic film, but is not deflected by a magnet. *P. Villard*

1900 A body seems to absorb or emit energy in whole number multiples of a definite amount or quantum. *M. Planck*

1900 The mass of an electron seems to increase with increases in its velocity. *W. Kaufman*

1900 A charged electroscope tends to discharge even when precautions are taken to prevent access of all known ionizing radiation. *C. T. R. Wilson, J. Elster, and H. Geitel*

1900 Radioactivity is not an inherent property of uranium but seems to be due to a substance associated with it. *W. Crookes*

1900 Thorium salts liberate a radioactive gas which decays rapidly but leaves an induced activity on surrounding matter. *E. Rutherford*

1900 Radium and actinium liberate a radioactive gas similar to that liberated from thorium. *E. Dorn and A. Debierne*

1901 Although a uranium sample can be "scrubbed" clean of its radioactivity, it recovers the property. *H. A. Becquerel*

1902 Each atom of a radioactive substance seems to be a constant source of energy. *P. and M. Curie*

1902 The atoms of radioactive elements undergo spontaneous disintegration with the expulsion of charged particles and leave behind new lighter elements. How many atoms disintegrate in a unit of time depends on how many atoms were present at that time. *E. Rutherford and F. Soddy*

1903 An electroscope on the surface of frozen Lake Ontario or surrounded by thick layers of iron and lead still discharges slowly. *J. C. McLennan, E. F. Burton, E. Rutherford, and H. L. Cook*

1903 Alpha rays can be deflected by a powerful magnetic field in a direction opposite to that of a stream of electrons. *E. Rutherford*

1903 Alpha rays resembles canal rays and, thus, are similar to ionized hydrogen atoms. *E. Rutherford*

1903 There is no reason to assume that an enormous store of energy is possessed by radioelements alone. *E. Rutherford and F. Soddy*

1903 The luminescence produced on zinc sulfide screens by alpha particles consists of a large number of individual flashes. *W. Crookes, J. Elster, and H. Geitel*

1904 Perhaps the energy associated wth radioactivity results from positive and negative charges being mutually annihilated. *J. H. Jeans*

1904 The atom seems to consist of a positively charged center attracting negatively charged particles whirling around it. *H. Nagaoka*

1904 The atom seems to consist of a number of negative corpuscles moving about in a sphere of positive electrification with the corpuscles arranged in a series of concentric shells. *J. J. Thomson*

1904 Radioactive atoms seem to have a mean average life such that the fraction decaying in a unit time/multiplied by the average life equals unity. *F. Soddy*

1904 Since it is always found in uranium minerals, radium may be a descendant of uranium. *E. Rutherford*

1904 A constant (half-life) can express the time for any radioactive sample to be reduced by one-half. *E. Rutherford*

1904 The distribution of radioactive elements in biological material may be studied by their effects on photographic film. *E. London*

1905 Energy seems to be propagated through space in definite quanta or photons moving with the speed of light. *A. Einstein*

1905 An observer will always find the velocity of light to have the same value regardless of the observer's motion. *A. Einstein*

1905 Since the mass of a body as a result of its motion is directly related to its kinetic energy, it appears that a mass moving at the speed of light squared would be converted into energy. *A. Einstein*

1905 The thickness of an element required to stop alpha particles is proportional to the square root of the atomic weight of the element. *W. H. Bragg*

1906 Since the mass/charge ratio for alpha particles is about one-half that for the proton, perhaps an alpha particle is a helium atom. *E. Rutherford*

1906 High velocity alpha particles shot through gold foil only 5×10^{-6} cm. thick are deflected 90° or more. *H. Geiger and E. Marsden*

1907 An element, ionium, lies between uranium and radium. *B. B. Boltwood*

1907 Two radioelements may differ in their radioactivity but be identical chemically. *H. N. McCoy and W. H. Ross*

1907 Lead seems to be the final product of uranium disintegration. The age of a radioactive mineral can be determined from the known half-life of the parent. *B. B. Boltwood*

1908 The charge on an alpha particle is half that of the proton and, therefore, its mass is four times larger. *E. Rutherford, H. Geiger, and E. Regener*

1909 As proof of the relationship between alpha particles and helium atoms, helium gas collects in a tube surrounding a thin-walled tube containing an alpha-emitting substance. *E. Rutherford and T. Royds*

1910 The path of alpha particles through silver halide photographic emulsions appears as thin black lines. *S. Kinoshita*

1910 The energy of an alpha particle at its source can be estimated by how far it travels before losing its ionizing power. *H. Geiger*

1910 There appear to be several cases where completely different radioelements have identical chemical properties. *F. Soddy*

1911 Each element when used as the target in an X-ray tube forms a characteristic spectrum of rays. The higher the atomic weight, the higher the energy needed to produce X-rays. *C. G. Barkla*

1911 The atom contains a central positive charge (nucleus) distributed through a very small volume. *E. Rutherford*

1911 There appear to be half as many electrons in the atoms of the lighter elements as the weight of the atom. *C. G. Barkla*

1911 The range of an alpha particle is related to the ratio between the number of atoms disintegrating in a given interval and the number of radioactive atoms present. *H. Geiger and J. M. Nuttall*

1911 Individual charged particles leave visible trails when passing through water-saturated air. *C. T. R. Wilson*

1911 The discharge of an alpha particle drops a radioelement two places down the periodic table. *F. Soddy*

1911 Electroscopes in high altitudes tend to discharge even more rapidly than at the earth's surface. *T. Wulf and A. Gockel*

1912 Diffraction grating spectra of X-rays suggest they are similar to light but with shorter wave length. *M. von Laue*

1912 The diffraction spectrum produced when X-rays pass through a crystal is a function of X-ray wave length and regular spacing of atoms, ions, or molecules. *W. L. Bragg*

1913 There seem to be as many positive charges on the nucleus of an atom as the position the atom holds in the ascending periodic tables. *A. Van den Broek*

1913 An electron appears to radiate no energy while moving in a closed orbit but will emit a spectral line of definite frequency when jumping from a higher to lower state. *N. Bohr*

1913 The charge on the nucleus of an atom increases by regular steps as we pass from one element to the next. *H. G. J. Moseley*

1913 Extranuclear electrons, particularly those in the outermost shells of an atom are responsible for its chemical and spectral properties. *N. Bohr, E. Rutherford, and J. J. Thomson*

1913 The loss of a beta particle seems to advance a radioelement one place up the periodic table. *A. Fleck*

1913 A ray of positive particles from neon gas in a discharge tube shows the gas to be a mixture of two gases with molecular weights of 20 and 22. *J. J. Thomson*

1913 All elements falling in the same place in the periodic table (isotopes) are chemically identical and nonseparable by chemical means. *F. Soddy*

1913 If two conducting electrodes—an emitter coated with a beta active material, and a collector—are separated by a nonelectrolyte, electrons will flow between the electrodes. *H. G. J. Moseley*

1913 Lead 210 added to other lead salts can serve as a radioactive tracer. *G. Hevesy and F. Paneth*

1914 Gamma rays can be deflected by X-ray deflecting crystals. *E. Rutherford and A. N. da C. Andrade*

1914 The atomic weight of lead formed as the end product of thorium is one unit higher than ordinary lead. *F. Soddy and H. Hyman*

1914 Lead derived from uranium minerals is one unit lower in atomic weight than ordinary lead. *T. W. Richards and M. E. Lembert*

1915 If four gram-atoms of hydrogen were to form one gram-atom of helium, nearly 10^{12} calories of heat would be released. *W. D. Harkins and E. D. Wilson*

1917 Alpha particles passing through air seem to dislodge hydrogen atoms from nitrogen atoms. *E. Rutherford*

1918 Several different radioelements seem to have the same atomic weight. *A. W. Stewart*

1919 Perhaps isotopes can be separated by high-speed centrifuges. *F. A. Lindemann and F. W. Aston*

1919 If a gaseous mixture of isotopes is placed in a vessel, part of which is hotter than the remainder, the lighter molecules should concentrate in the hotter regions. *D. Enskog and S. Chapman*

1920 There may be a hitherto undiscovered particle (neutron) resulting from the neutralization of a proton by an electron. *W. E. Harkins, Orme Masson, and E. Rutherford*

1920 Stars seem to draw from some vast store of energy, perhaps the energy liberated when hydrogen forms helium. *A. S. Eddington*

1921 The isotopes of chlorine can be enriched selectively by diffusion through clay pipes. *W. D. Harkins*

1923 When X-rays fall on carbon or other low atomic-weight materials, the scattered radiation contains some rays of longer wave length than the incident X-rays. *A. H. Compton*

1923 Atomic particles seem to exhibit both material and wave-like characteristics. *L. de Broglie*

1923 Lead 212 can be taken up by plants and traced by using its radioactive characteristic. *G. Hevesy*

1924 Many of the lighter elements emit protons when bombarded with alpha particles. *E. Rutherford and J. Chadwick*

1924 If a radioactive gas flows between two electrodes which differ markedly in the amounts of energy required for the release of orbital electrons, a potential difference will be developed between the electrodes. *J. V. Kramer*

1924 Radioactive polonium can be injected into various organs to study its effects. *A. Lacassagne and J. Lattes*

1925 The first shell can accommodate no more than 2 electrons; the second, 8; the third, 18; the fourth, 32; and the fifth, 50. *W. Pauli*

1925 When an alpha particle strikes an atomic nucleus it can be absorbed; whereupon the nucleus emits a proton. *P. M. S. Blackett*

1925 High energy ionizing radiations come from outer space and they may be called cosmic rays. *R. A. Millikan*

1926 The chance of finding a specific particle at a specific place at a particular time can be expressed in terms of statistical probability. *E. Schrodinger*

1927 A beam of electrons reflected and scattered by a nickel crystal shows wave-like properties. *L. H. Germer and C. J. Davisson*

1927 A beam of electrons moving rapidly through a very thin sheet of metal shows diffraction patterns in photographic film. *G. P. Thomson*

1927 One cannot picture accurately the velocity or energy of a particle if the picture-bringing device reacts with the particle. *W. Heisenberg*

1927 The rate with which mutations appear in fruit flies can be increased by exposure to X-rays. *H. J. Muller*

1927 The atomic weight of hydrogen is 1.00778. *F. W. Aston*

1927 There seems to be a certain amount of mass converted to energy to bind the protons and neutrons together in the nucleus. *F. W. Aston*

1927 There are occasional bursts of electrometer current in ionization chambers which are so arranged as to react to the passage of cosmic rays. *G. Hoffmann*

1927 There seems to be a noticeable decrease in the intensity of cosmic rays, as observed on shipboard, in the region of the magnetic equator. *J. Clay*

1927 If the Wilson cloud chamber is modified by filling the chamber with gas at high pressure, perhaps cosmic rays will form sufficient ions along their paths to become visible. *D. Skobelzyn*

1928 If two or more Geiger-Mueller tubes oriented horizontally and stacked, one on top of the other and arranged electronically to trigger a count only when struck by a particle or ray of sufficient energy to pass through all the tubes (a cosmic ray telescope), perhaps we cannot only count cosmic rays but also determine the direction from which they are coming. *W. Bothe and W. Kolhorster*

1929 Nuclear fusion reactions may be the source of stellar energy. *R. Atkinson and F. Houtermans*

1929 The atomic weight of hydrogen seems to be 1.00751. *F. W. Giaque and H. L. Johnston*

1929 There is a resonant energy (resonance peak) that allows a bombarding particle the greatest chance of entering an atomic nucleus. *R. W. Gurney*

1930 Alpha particles striking light elements like beryllium produce a highly penetrating radiation. *W. Bothe and H. Becker*

1930 A strong alternating magnetic field can impart added energy to particles moving in a spiral path (cyclotron). *E. O. Lawrence*

1930 There may be a particle similar to the electron but carrying a positive charge. *P. A. M. Dirac*

1930 Just as surface tension keeps water drops in spherical form, so do nuclear forces keep the nucleus spherical. *G. Gamow*

1930 If cosmic rays contain a large proportion of electrically charged particles, the earth's magnetic field should deflect them eastward or westward according to the nature of their charge. *B. Rossi*

1930 Since matter seems to absorb high-energy gamma rays at a greater rate than expected, perhaps the gamma rays are converted into positron-electron pairs. *C. Y. Chao*

1931 There may be one part of a heavy hydrogen isotope in every 4,500 parts of hydrogen. *R. T. Birge and D. H. Menzel*

1931 There is a line in the hydrogen spectrum that suggests a hydrogen isotope (deuteron) of weight 2. *H. C. Urey, F. G. Brickwedde, and G. M. Murphy*

1931 Water in long-standing electrolytic cells may be appreciably denser than ordinary water. *E. R. Smith*

1931 Potentials as great as 1.5 million volts can be obtained from special static machines (Van de Graaff generator). *R. J. Van de Graaff*

1931 Ionized particles can be given added energy by passing them through a series of charged cylinders (linear accelerator). *D. H. Sloan and E. O. Lawrence*

1931 Energy released during beta decay suggests existence of neutrinos—particles of vanishingly small mass and capable of passing through billions of miles of solid matter. *E. Fermi and W. Pauli*

1932 The nucleus contains protons and neutrons adequate to form the total weight of the atom. *W. Heisenberg*

1932 The separation of isotopes by diffusion can be improved by recycling the mixture through a cascade of diffusion barriers. *G. Hertz*

1932 Protons accelerated by high voltages can split lithium atoms. *J. D. Cockcroft and E. T. S. Walton*

1932 Protons are ejected from hydrogen-containing materials, particularly paraffin, if it is placed in the path of the new Bothe-Becker radiation. *I. Joliot-Curie and F. Joliot*

1932 The Bothe-Becker radiation appears to be neutrons, that is, particles of mass nearly that of the proton but with no charge. *J. Chadwick*

1932 Neutrons can liberate alpha particles from atomic nuclei. *N. Feather, W. D. Harkins, D. M. Gans, and H. W. Newson*

1932 There is a possibility that the neutrons may occupy quantum groups or shells just as do the extranuclear electrons in atoms. *T. Bartlett*

1932 A cloud chamber trail was photographed that could be best interpreted as left by a particle (positron) with a positive charge and mass equal to that of the electron. *C. D. Anderson*

1933 The 0.0185 unit of mass lost when a lithium atom splits is converted into enough energy to prove Einstein's $E=mc^2$ equation. *K. T. Bainbridge*

1933 Cloud chamber trails suggest that electron-positron pairs can be formed. *P. M. S. Blackett and G. P. S. Occhialini*

1933 High energy gamma rays from thorium-C, like cosmic rays, can produce positron-electron pairs. *I. Joliot-Curie and F. Joliot*

1933 A positron and electron can unite to produce nothing but annihilation energy. *J. Thibaud and F. Joliot*

1933 The formation and annihilation of positron-electron pairs can become proof of Einstein's $E=mc^2$ equation. *P. M. S. Blackett and G. P. S. Occhialini*

1933 An electrically charged particle undergoing rotation of some kind will act like a small magnet. *O. Stern and I. Estermann*

1933 If the passage of a cosmic ray through Geiger-Mueller tubes can trigger a camera which is focused on a cloud chamber that is also in the path of the cosmic ray, the ray can be made to record its own vapor trail. *P. M. S. Blackett and G. P. S. Occhialini*

1933 If a stream of positrons is allowed to impinge upon a metal surface, they appear to be annihilated, leaving only annihilation radiation. *J. Thibaud and F. Joliot*

1934 Water and other transparent substances emit a weak bluish-white glow when exposed to gamma radiation. *P. A. Cerenkov*

1934 The isotopes of lithium can be separated by using an adaptation of the mass spectrograph. *M. L. Oliphant, B. S. Shire, and B. M. Crowther*

1934 Radioactive isotopes may be formed in nature by the action of cosmic rays. *A. Grosse*

1934 If a number of electrically charged particles are moving in such a way as to represent an electric current flowing in one direction, a magnetic field is produced which tends to pinch or confine the particles by self-constriction. *W. Bennett*

1934 Deuterium bombarded by deuterons produces a third isotope of hydrogen (tritium) with mass number 3. *E. Rutherford, M. L. Oliphant, and P. Harteck*

1934 Gamma rays from thorium-C can split a deuterium nucleus into a neutron and a proton. *J. Chadwick and M. Goldhaber*

1934 The neutron seems to have a mass of 1.00897. *J. Chadwick and M. Goldhaber*

1934 Uranium bombarded with slow neutrons seems to yield several elements. *E. Fermi*

1934 Perhaps Fermi succeeded in splitting the uranium atom into two approximately equal halves. *I. Noddack*

1934 The e/m for the positron does not differ by more than 15 percent from that of the electron. *J. Thibaud*

1934 Chemical bonds can be broken by the recoil of a nucleus which has emitted a gamma ray. *L. Szilard and T. A. Chalmers*

1935 Radioactive phosphorus can be used to study the absorption of this element by plants. *G. Hevesy and O. Chiewitz*

1935 Observations taken with a cosmic ray telescope confirm that more rays approach the earth from the west than from the east, thus proving that the rays must be positively charged and hence are deflected by the earth's magnetic field. *T. H. Johnson*

1935 Electrons to which cosmic rays may have imparted energies of billions of electron volts may trigger a shower of ionizing radiation as they pass through lead plates. This radiation in turn, will trigger subsequent showers as it passes through up to 10 centimeters of lead. If a series of lead plates can be arranged in a cloud chamber the cascade shower can be observed. *P. Augér*

1935 A short, heavy track was observed in a cloud chamber exposed on Pike's Peak which could be attributed to neither a proton nor an electron but suggested a negatively charged particle lighter than a proton but heavier than an electron. At the same time, but independently, a photograph was obtained of a cloud chamber through which a cosmic ray had passed through 11 centimeters of lead, leaving a path at the end which seemed to be caused by a negative particle having about 130 times the mass of the electron. *C. D. Anderson, S. H. Neddermeyer, J. C. Street, and E. C. Stevenson*

1935 In light of the remarkable forces which hold the nucleus together, there may be a heretofore unidentified charged particle having a mass about 200 times that of the electron. *H. Yukawa*

1935 Deuterons fired from a cyclotron create nuclear changes more efficiently than one would predict. *E. O. Lawrence, E. M. McMillan, and R. L. Thornton*

1935 In deuterons, the protons are not very tightly bound to the neutrons, thus allowing the neutron to go on whizzing into a nucleus even though the proton is repelled. *J. R. Oppenheimer and M. Phillips*

1935 High speed neutrons can be slowed down to thermal values by passing them through hydrogen-containing substances. *E. Amaldi, O. D' Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, and E. Segre*

1935 Perhaps nuclear forces are transmitted between neutrons and protons by as yet undiscovered particles (mesons). *H. Yukawa*

1936 Characteristics of cosmic rays can be studied by their effects on thick packs of photographic plates kept in a light-tight box. *M. Blau*

1936 The probability of capture of a neutron by a given nucleus can be predicted if the energy of the neutron and the resonance peak of the given nucleus are known. *G. Breit and E. P. Wigner*

1936 When a foreign particle enters a nucleus, the excess energy is shared among the nucleons in the resulting compound nucleus. *N. Bohr*

1936 Neutrons show diffraction patterns with sodium chloride crystals. *N. P. Mitchell and P. N. Powers*

1936 A thin paste of ZnS ZnO in castor oil, when spread on a metal plate, covered with a sheet of mica, and immersed in salt water, will electroluminesce. *G. Dessauer*

1936–37 Sometimes, as cosmic rays pass through cloud chambers or photographic emulsions, they form several tracks meeting at a point—cosmic ray stars which suggest that the rays have caused nuclear disintegrations or explosions. *M. Blau and H. Wambacher*

1937 Since some cosmic rays penetrate lead plates without producing cascade showers, perhaps there are several kinds of particles in cosmic rays. *L. Fussell*

1937 The radiation described by Cerenkov in 1934 arises when electrically charged particles travel through a medium with a velocity greater than that of light in that medium. *I. Frank and I. Tamm*

1937 Since nearly twice as much energy is supplied as is gained from splitting a lithium atom with deuterons, the outlook for gaining useful energy is not promising. *E. Rutherford*

1937 A very fine, metal-coated, quartz fiber attached to a rigid metal wire can become a good electroscope. *C. C. Lauritsen*

1938 By the use of deuterium and stable nitrogen 15 tracers, it can be shown that there is a continual interaction among the fats, proteins, and carbohydrates already present in an animal body and those ingested in the form of food. *R. Schoenheimer and D. Rittenberg*

1938 The products from Fermi's 1934 experiment seem to be radium isotopes. *O. Hahn and F. Strassman*

1938 Although matter can be converted to energy, the prospects for destroying nuclear matter for power purposes are no brighter than those for cooling the ocean and extracting the heat for profitable work. *E. O. Lawrence*

1938 Cosmic radiation contains the kinds of particles predicted by Yukawa in 1935. *C. D. Anderson, S. H. Neddermeyer, J. C. Street, and E. C. Stevenson*

1939 The different energy levels at which a nucleus can exist can be determined by passing a beam of atoms through a strong, uniform magnetic field upon which is superimposed a weak field, oscillating with a frequency that can be varied so as to find the frequency at which the nuclei absorb maximum energy from the field. *I. Rabi*

1939 The products of Fermi's 1934 experiment must have been Ba, La, and Cd. *O. Hahn and F. Strassmann*

1939 When a uranium atom splits, more energy is released than by any other fission process. *L. Meitner and O. R. Frisch*

1939 Ionization oscillograms show about 170 Mev energy per fission of uranium atoms. *W. Jentschke, F. Prankl, E. T. Booth, J. R. Dunning, and F. G. Slack*

1939 The neutrons liberated during uranium fission can form a chain reaction, the fission of one gram of U^{235} yielding roughly 1,000 kilowatts of energy. *H. von Halban, F. Joliot, L. Kowarski, and E. Fermi*

1939 A chain reaction might be controlled by introducing a substance like cadmium to absorb the slow neutrons. *F. Adler, H. von Halban, and F. Perrin*

1939 Calorimetric measurements show that 175 Mev are liberated when a uranium atom splits. *M. C. Henderson*

1939 Carbon in the form of graphite may slow down enough of the neutrons to maintain a chain reaction in uranium fission. *E. Fermi and L. Szilard*

1939 When a neutron splits an uranium atom, two new neutrons may be released which could split other uranium atoms. *H. von Halban, F. Joliot, and L. Kowarski*

1939 The larger the ratio between the atomic number squared (Z^2) and the mass number (A) of an atom, the smaller the energy required to make it split. *N. Bohr and J. A. Wheeler*

1939 If uranium is enriched in U^{235}, fewer of the newly released neutrons would be captured by U^{238} atoms and more would continue to cause thermal fission of U^{235}. *E. Fermi*

1939 If fairly large lumps or rods of uranium are embedded in a mass of graphite, a maximum number of neutrons would be slowed down enough to create a chain reaction. *E. Fermi*

1939 The rate at which the sun produces energy can be theoretically duplicated in a reaction in which hydrogen atoms, using C^{12}, with C^{13}, N^{14}, O^{15} and N^{15} as intermediate steps, are fused to form helium. *H. A. Bethe*

1939 It may be possible to build extremely powerful bombs which, although too heavy for air transport, could be carried by boat and exploded in a port and might very well destroy the whole port together with some of the surrounding territory. (Letter to President Roosevelt.) *A. Einstein*

1939 An Advisory Committee on uranium was appointed by President Roosevelt.

1939 President Roosevelt was advised to expedite procurement of 4 tons of pure graphite and 50 tons of uranium oxide for research on the absorption cross section of carbon.

1940 Uranium when exposed to slow neutrons produces a 2.3-day beta decay product. The decay product appears to be element 93 (neptunium). *E. McMillan and P. Abelson*

1940 Uranium 238 undergoes spontaneous fission at a rate such that one gram yields about 25 fissioning nuclei each hour. *G. Flerov and K. Petrjak*

1940 The 235 isotope of uranium can be separated by the mass-spectrograph method. *O. A. Nier, K. H. Kingdon, and H. C. Pollock*

1940 When molecules and ions of a gas come to equilibrium in a solution, the heavier isotopes tend to stay in ions. *H. C. Urey*

1940 Electrons can be accelerated in a doughnut-shaped tube forming the secondary coil of a high-voltage transformer (betatron). *D. W. Kerst*

1940 The U^{235} isotope will fission when struck by neutrons which lack enough energy to split U^{238} atoms. *E. T. Booth, J. R. Dunning, and A. V. Grosse*

1940 A chain reaction might be maintained with uranium salts in heavy water. *H. von Halban*

1940 The U. S. Army and Navy allocated $6,000 to purchase uranium research materials.

1940 Physicists voluntarily agreed to withhold publication of all papers dealing with uranium fission.

1940 The United States learned that a large section of the Kaiser Wilhelm Institute in Berlin had been designated for research on uranium.

1941 A cube of graphite containing about 7 tons of uranium oxide in iron vessels distributed throughout the cube created a neutron flux throughout the cube adequate to calculate the infinite multiplication factor required to set up a chain reaction. *E. Fermi*

1941 If neptunium 239 decays by beta emission, element 94 should be formed and an appropriate name for the new element would be plutonium. *G. T. Seaborg, E. M. McMillan, J. W. Kennedy, and A. C. Wahl*

1941 A cube of graphite, containing several tons of not-too-pure uranium oxide distributed at equal distances throughout the cube when triggered with a radium-beryllium source of neutrons, came within 13 percent of producing as many neutrons as were captured. *E. Fermi*

1941 When U^{235} atoms undergo fission and the new neutrons are captured by U^{238} nuclei, a new element, plutonium, is formed, which promises to fission with super-bomb effects. *E. O. Lawrence*

1941 Norway is producing several kilograms of heavy water per day, Germany has ordered considerable quantities of heavy hydrogen paraffin, and the possibilities of a U^{235} chain reaction look good. *J. Chadwick, G. Pegram, and H. C. Urey*

1941 Sixteen projects totalling about $300,000 were financed by the U. S. Government to determine the feasibility of an atom bomb.

1941 If all possible effort is spent on the program, fission bombs may be available in 3 or 4 years. *National Academy of Science Committee*

1942 Solid materials subjected to high energy particles, such as neutrons, may have their atoms displaced in the crystal lattice with a subsequent change in the properties of the material. *E. Wigner*

1942 The presence of high-radiation flux may cause changes in the mechanical properties of reactor materials. *F. H. Spedding and E. Teller*

1942 By using diffusion barriers with passages about 1.0×10^{-6} cm. in diameter (made by acid etching thin sheets of silver-zinc alloy) the three isotopes of uranium, 234, 235, and 238, can be separated. *E. T. Booth, H. C. Paxton, and C. B. Slade*

1942 A selfmaintaining nuclear chain reaction will occur in a pile of graphite blocks interspersed with 12,400 pounds of lumps of uranium and uranium oxide and can be kept under control by inserting or withdrawing cadmium strips also interlaced through the pile. *E. Fermi*

1942 A number of kilograms of U^{235} or plutonium would be fissionably explosive and equivalent to several thousand tons of TNT and there appear to be four feasible methods for making this material. *C. Bush and J. C. Conant*

1942 A special district of the Corps of Engineers (Manhattan) was organized and given funds and priorities adequate to prepare materials and build atom bombs.

1943 A graphite-moderated, air-cooled pile designed to operate at 1,000 kilowatts will produce plutonium and its neutron beams can be used to prepare a wide variety of isotopes.

1943 Uranyl sulfate or nitrate enriched in U^{235} and dissolved in water will maintain a chain reaction and the heat from this "water boiler" can be employed for useful purposes.

1944 In the hope of producing plutonium 241, uranium 238 was bombarded with 40-Mev alpha particles. Chemical separation of what should have been the plutonium 241 failed to produce a detectable beta-emitting material but it did show alpha activity. Presumably element 95, later to be named americum, was responsible for the alpha activity but the beta marking its decay from plutonium 241 was too weak to detect. *G. T. Seaborg, R. A. James, and L. O. Morgan*

1944 On the basis of a single cloud-chamber photograph, there seems to be, in cosmic rays, a particle with a mass about 1,000 times that of the electron. *M. L'Heretier and L. Leprince-Ringuet*

1944 A heavy water-moderated reactor can operate at the 250-kilowatt level.

1944 A reactor can be built using fissionable U^{235} to release energy and neutrons which, upon being captured by U^{238}, breed new fissionable plutonium to release still more energy.

1944 If plutonium 239 is bombarded with alpha particles, element 96 (curium) may be formed. *G. T. Seaborg, R. A. James, and A. Ghiorso*

1945 As much as 1.5 tons of uranium 238, suspended in a tank containing 1.5 tons of heavy water and provided with a graphite reflector, did not set up a chain reaction. *W. Heisenberg*

1945 Certain crystals which are normally poor electrical conductors gain conductivity proportionally to the intensity of ionizing radiations to which they are exposed. *P. J. Van Heerden*

1945 Individual ionizing particles may be counted by amplifying the pulses of current produced when certain crystals are exposed to the particle. *P. J. Van Heerden*

1945 First atomic bomb detonated.

1945 Atomic bombs dropped on Japan.

1946 Organic carbon may contain a small proportion of carbon 14, formed when the carbon was present as atmospheric carbon dioxide. *W. F. Libby*

1946 The age of certain ocean-bottom sediments, when determined by Libby's carbon 14 dating method, agrees with the age determined by measurements based on the content of thorium 230. *J. Kulp*

1946 If a material under investigation is surrounded by a coil of wire which carries a high-frequency, alternating current and if this coil, in turn, is placed in a strong magnetic field, there will be a frequency at which the magnetic moments of the nuclear particles of the investigated material will show magnetic resonance absorption and induction. *F. Bloch and E. Purcell*

1946 By feeding Pu^{239} into a reactor at a rate just adequate to maintain a chain reaction, a reactor can operate without a moderator.

1946 The ratio between carbon 14 and nitrogen 14 in organic material suggests the date the carbon was fixed in the material. *W. F. Libby*

1947 The temperature of the sea in which a prehistoric animal lived may be estimated from the ratio of the isotopes of oxygen in the fossil shell. *H. C. Urey*

1947 The slight discrepancies between theoretical and observed measurements of the magnetic properties of a rotating particle can be explained if we assume that the particle interacts with its own electromagnetic field. *H. Bethe and J. Schwinger.*

1947 Perhaps the particles in cosmic rays which carry either positive or negative charges, but are about 200 times as heavy as electrons, should be called "mesons." *H. J. Bhabha*

1947 Certain tracks recorded in photographic emulsions which were exposed at high altitudes in the Bolivian Andes suggest that cosmic rays contain high-energy mesons (pi-mesons), which slow down to become lower energy mesons (mu-mesons). *C. F. Powell and G. P. S. Occhialini*

1947 A V-shaped cloud chamber track suggests the existence in cosmic rays of a particle with 1,000 times the mass of the electron which decayed in flight into a pi-meson and another probably uncharged particle. A second track suggested the decay in flight of a neutral particle with a mass estimated to lie between 700 and 1,200 times that of the electron. A third track suggested the decay of a neutral particle (hyperon), with 2,000 times the mass of the electron, into a proton and negative pi-meson. *G. D. Rochester and C. C. Butler*

1947 Elements in the middle range of atomic numbers when bombarded by high energy alpha particles or by deuterons may break up into many small particles (spallation). *G. T. Seaborg and I. Perlman*

1948 The elements having the largest numbers of stable isotopes tend to be those having 20, 50, 82, or 126 ("magic numbers") of either neutrons or protons or both. *M. Mayer*

1948 Certain cloud-chamber tracks which resemble a hammer head suggest that cosmic rays can form lithium 8 nuclei which undergo beta decay to form beryllium 8. The latter nucleus is extremely unstable and splits immediately into two alpha particles which form the hammer head. *P. Frier, E. J. Lofgren, E. P. Ney, F. F. Oppenheimer, H. L. Bradt, and B. Peters*

1948 If a beam of 380-Mev alpha particles from the Berkeley synchrocyclotron are directed against the edge of a target, tracks definitely due to pi-mesons can be observed in a stack of photographic plates placed nearby. *E. Gardner and C. M. G. Lattes*

1948 A 6,000-kilowatt pile can produce plutonium and prepare radioisotopes; and the air for cooling the pile can be recirculated to warm the building where the pile is located.

1949 Energy levels within nuclei may be related to the coupling effect set up between the spin of each nucleon and its orbital momentum. *M. Mayer, O. Haxel, J. Jensen, and H. Suess*

1949 Perhaps cosmic rays derive their enormous energy by repeated interaction with the magnetic fields which H. Alfven thinks drift about among the stars. *E. Fermi*

1949–50 If americum 241 and curium 242 are bombarded with 35-Mev alpha particles, elements 97 (berkelium 243) and 98 (californium 245) will be formed. *S. G. Thompson, A. Ghiorso, G. T. Seaborg, and K. Street, Jr.*

1950 An odd nucleon may distort an otherwise spherical nucleus and thus produce an excited or unstable nucleus. *J. Rainwater*

1950 When targets of carbon, beryllium, or other elements are struck by protons which have been accelerated beyond 175 Mev, pi-mesons are formed which carry no electrical charge. *R. Bjorkland, W. E. Crandall, B. J. Moyer, H. F. York, J. Steinberger, W. K. H. Panofsky, and J. S. Steller*

1950 Low-power nuclear reactors can be operated and effectively shielded in 20-foot-deep swimming pools. *E. P. Blizard and C. E. Clifford*

1950 Knowing that positrons and electrons annihilate each other, we may suppose that perhaps some day the controlled release of the whole of the energy of the atom, by its complete destruction, could become a reality. *S. Glasstone*

1951 Deformations caused by the introduction of an odd nucleon tend to move over the surface of the nucleus in the form of waves somewhat like the oscillations on a deformed drop of water. *A. Bohr*

1952 Since the formation of a hyperon is generally accompanied by the formation of another particle, usually a heavy (K) meron, and vice versa, some kind of conservation principle is suggested. *A. Pais*

1952 A fission chain reaction was maintained in a water-circulating solution at high temperatures and pressures.

1953 Photographic emulsions exposed to cosmic rays at an altitude of 85,000 feet suggest the existence of nuclei of several light elements in which a neutron has been replaced by a neutral hyperon (hyperfragments). *M. Danysz and J. Pniewski*

1953 Although beta particles from any one isotope must have the same origin, they may be emitted with a range of energies if, at the time they are formed, neutrinos are also created which carry varying amounts of energy. The neutrino may be a particle which is present in both electrons and positrons. *E. Fermi*

1953 If neutrinos are created along with beta particles, during the operation of a reactor when large amounts of negative beta-emitting radioelements are formed, the neutrinos should be detectable because they might interact with protons, producing positrons and neutrons, the positrons, in turn, encountering positron-electron annihilation with subsequent production of protons which can be registered on a scintillation counter. *F. Reines, C. L. Cowan, and others*

1953 Atomic explosives can be adapted to fit artillery weapons.

1953 The thermonuclear reaction can be successfully adapted to military weapons (H bombs).

1954 Human beings subjected for several hours to the fine ash falling out of hydrogen-bomb clouds will die. *A. Kuboyama*

1954 The nucleus, when under impact by a neutron, behaves something like a cloudy crystal ball that is being struck by light waves. All of the energy of the neutron is shared rapidly among the nucleons and the energy will be absorbed or reflected according to whether the incoming and nuclear waves are in or out of phase. *H. Feshbach, C. Porter, and V. Weisskopf*

1954 Elements 99 and 100 can be created artificially by bombarding uranium 238 with 100-Mev ions of nitrogen 14 in a 60-inch cyclotron.

1955 The large numbers of high- and low-energy neutrons produced by thermonuclear bombs may lead to successive neutron capture by heavy nuclei and produce elements 99 (einsteinium) and 100 (fermium). *Los Alamos and Argonne National Laboratories*

1955 If a billion or so atoms of einsteinium 253 are deposited on gold foil and bombarded with 48-Mev alpha particles, perhaps at least one atom of element 101 (mendelevium) could be collected, by recoil, on an adjacent gold foil. *A. Ghiorso, B. G. Harvey, G. R. Choppin, S. G. Thompson, and G. T. Seaborg*

1955 Particles issuing from a copper block under bombardment by high energy protons from the Bevatron show the characteristics of antiprotons as hypothesized by Dirac in 1930. *O. Chamberlain, E. Segre, C. E. Wiegand, and T. Ypsilantis*

1955 Photographic film exposed to a stream of particles containing what were supposed to be antiprotons revealed stars which can best be explained as the mutual annihilation of proton-antiproton pairs. *E. Amaldi*

1955 A mixture of isotopic molecules in the gaseous state may be separated by passing the mixture through an expanding air nozzle at pressures below atmospheric. The lighter molecules tend to concentrate at the outside of the gas stream and can be drained off. *E. W. Becker and collaborators*

1955 An amount of nuclear fuel "about the size of a softball" kept a nuclear-powered submarine going for some 60,000 miles throughout a 2-year period.

1955 Element 101, mendelevium, artifically created by bombarding $_{99}E^{253}$ with helium ions. *G. T. Seaborg*

1955 Cosmic ray particles passing through superheated ether form bubble trails that can be photographed as in a cloud chamber. *D. A. Glaser*

1956 Since the earth's magnetic field has been decreasing steadily through the last two or three centuries, there would have been a corresponding increase in the number of cosmic rays reaching the atmosphere and, consequently, ages determined by the carbon 14 method would be in error. *W. Elsasser, E. P. Ney, and J. R. Winckler*

1956 A mu-meson can act as a sort of catalyst in fusing, at low temperatures and low energies, one, and sometimes two, deuteron-proton pairs. *L. Alverez*

1956 A beam of antiprotons from the Berkeley Bevatron, impinging on liquid hydrogen, formed scintillations in a detector, which can best be interpreted as being caused by the mutual annihilation of a neutron and an antineutron. *B. Cork, Y. Lamberton, O. Piccioni, and W. Wenzel*

1956 An accurate description of a particle may hinge solely on whether a right- or left-handed frame of reference is used. *T. D. Lee and C. N. Yang*

1956 An experimental boiling-water reactor became critical and first generated electricity.

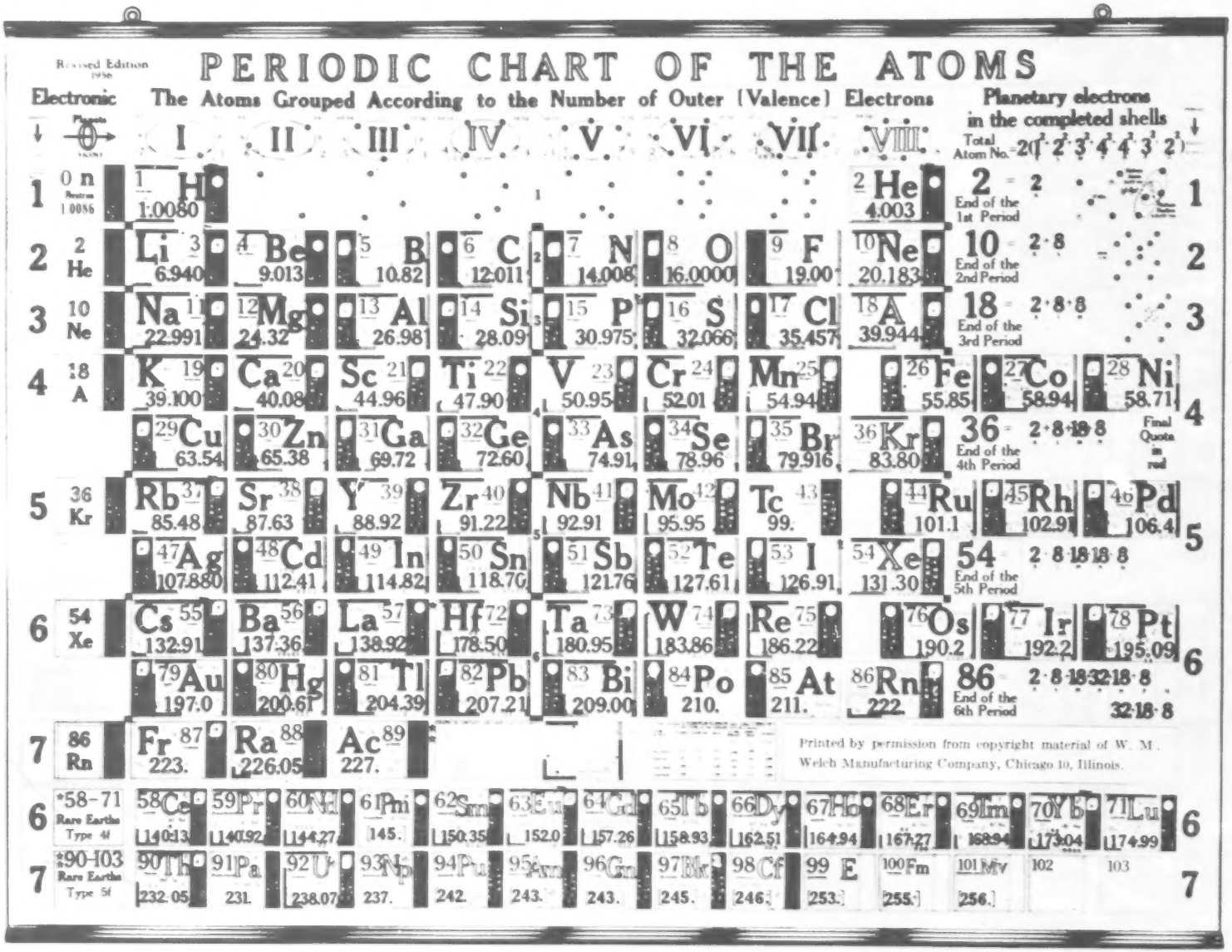
1956 The world's first full-scale nuclear reactor commenced official operation at Calder Hall, England.

1956 Uranium ore production in the United States reached nearly 3,000,000 tons per year.

1956 The United States offered for sale for peaceful purposes 40,000 kilograms of uranium 235, one-half for use in foreign countries.

1957 If curium 244 can be bombarded for use for half an hour or so with carbon 13 ions which have been boosted to energies between 65 and 100 Mev, perhaps element 102 (nobelium) will be formed. *P. R. Fields, A. M. Friedman, Colleagues of J. Milstead at the British Atomic Energy Research Establishment, and the Swedish Nobel Institute of Physics*

1957 If cobalt 60, a negative beta emitter, is kept at 0.01° C. above absolute zero to diminish random arrangement of the nuclei, and surrounded by a magnetic field so as to align the nuclear magnets parallel to the field, the beta particles are emitted in one direction, suggesting that all nuclear magnets were spinning in the same direction. Cobalt 58, a positive beta emitter, when subjected to the same experiment, emits its betas in the opposite direction. This suggests that neutrinos and antineutrinos differ only in direction of spin. *C. S. Wu, E. Ambler, and associates*



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